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NUCLEAR REGULATORY COMMISSION
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MEMORANDUM FOR: All Project Directors

50-416

THRU: Robert A. Capra, Director
RAC
Project Directorate I-1
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

FROM: Francis J. Williams Jr., Project Manager
Project Directorate I-1
Division of Reactor Projects - I/II
Office of Nuclear Reactor Regulation

SUBJECT: STATUS REPORT - BWR JET PUMP HOLD-DOWN BEAM FAILURES

This provides information to boiling-water reactor (BWR) Project Managers (PMs) for General Electric (GE)/BWR/3s, 4s, 5s, and 6s on staff activities related to the most recent failure of a jet pump hold-down beam which occurred at Grand Gulf, September 1993. Although the staff's preliminary assessment of this issue is that it is not safety significant, several concerns will be evaluated as part of the NRC Action Plan which is included in the attached staff report, BWR JET PUMP HOLD-DOWN BEAM FAILURES. This report provides a summary of the jet pump hold-down beam failure history, a description of the recent Grand Gulf incident, the NRC's plan to address the issue, and a preliminary assessment of the issue, and its safety significance.

Also attached is NRC Information Notice 93-101: JET PUMP HOLD-DOWN BEAM FAILURE which was issued on December 17, 1993, to alert licensees of BWRs to the issue; and GE's Rapid Information Communication Services Information Letter (RICSIL) No. 065 which updated RICSIL No. 330, Supplement 2.

This issue was also discussed with the Boiling Water Reactor Owners Group (BWROG) at a recent meeting which had been scheduled to discuss the BWR shroud cracking issue but which was expanded to include the hold-down beam cracking under the more general issue of BWR internals problems. The significant information relative to the hold-down beams was GE's announcement that the development and testing of an inspection technique (eddy current) to examine the ends (new failure location at Grand Gulf) of the hold-down beams for indications was almost complete.

The issue has not been designated as an MPA and no TACs are assigned. Although no requirements have been issued it is requested that BWR PMs remain aware of the issue and follow their licensee's activities regarding the jet pump hold-down beams during future shutdowns. As noted in the attached staff report, the BWROG has been requested to obtain the information from GE needed to categorize the existing hold-down beams including design, heat treatment, and operating hours. It is expected to be sent to the NRC soon and it will be distributed to BWR PMs upon receipt. Regarding the following of licensee activities during future shutdowns where the reactor vessel head is removed,

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the following information should be obtained and provided to F. Williams, 14B2, and J. Davis, 7D4, to enable the NRC staff to maintain a current status of the jet pump hold-down beam issue:

1. Were the hold-down beams examined?

2. If examined, by what method; visual, ultrasonics, or eddy current, and was the examination performed with the hold-down beams in place? What were examination results?

3. Were the hold-down beams replaced?

4. If replaced, with what design, heat treatment, and pre-load?

The status of this issue will be updated as appropriate.

The request for information from Project Managers has been approved by the Acting Associate Director for Projects.

Robert A. Capra for

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Project Directorate I-1
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Enclosures:
1. Staff Report, JET PUMP HOLD-DOWN BEAM FAILURES
2. NRC Information Notice 93-101
3. GE RICSIL No. 065

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BWR JET PUMP HOLD-DOWN BEAM FAILURES

I INTRODUCTION

The purpose of this report is to provide a preliminary assessment of the jet pump hold-down beam cracking issue and its safety significance. A summary of the jet pump hold-down beam failure history and a description of the recent Grand Gulf incident are provided. The staff action plan to address this issue is also identified in this report.

II DESCRIPTION OF JET PUMP HOLD-DOWN BEAM AND ITS FUNCTION

A schematic of the jet pump assembly is shown in Figures 1, 2 and 3. Flow from the recirculation pumps is distributed to the jet pump risers within the reactor vessel. The flow splits at the transition piece, makes a 180° bend in the elbow (ram's head) assembly, and passes out of the nozzle in the throat of the mixer assembly. The drive flow and suction flow are mixed in the mixer throat section. The total flow then passes through the jet pump diffuser section into the lower plenum area. The jet pump assembly allows the inlet mixer section to be removed for in-service inspection. This is accomplished by mechanically clamping the inlet-mixer to the riser subassembly with a remotely operable beam-bolt arrangement which transmits a preload downward clamping force (see Figures 4 and 5.). The preloading used is in the range of 25,000 to 30,000 inch-pounds. This is approximately three times the sum of the upward pressure forces and reaction force of the inlet-mixer and ensures minimal leakage at the spherical sealing joint between the two subassemblies. A lock welded keeper piece over the bolt prevents rotation of the bolt thereby maintaining the beam load. A pair of lock welds are provided to prevent rotation. These welds are sized such that together they withstand a minimum of 150 ft-lbs of torque. The lower discharge end of the mixer is slip fit into the diffuser portion of the jet pump and laterally held by a restrainer bracket subassembly which must be opened for mixer removal. The diffuser section of the pump is welded in place at the lower end to the annulus baffle plate.

The hold-down beam is made of Inconel X750 and weighs approximately 30 lbs and is approximately 1 foot long and 2 inches thick in the middle and 1 inch thick at the beam ends. The beam ends fit into the beam pockets of the ram's head transition piece and the beam load is transferred to the elbow though a bolt located in the center of the beam. The beam is loaded by an installation tool that pulls up on the beam trunnions. Once the proper preload is established, the bolt is screwed down against a spherical washer in the elbow and a bolt keeper is installed and tack welded to lock the beam bolt in place. Hydraulic forces on the elbow increase the beam load slightly above the preload value. The beam loading can be modelled as a four point load as indicated by the force arrows in Figure 5. The maximum beam tensile stress occurs at the minimum ligament on the top of the beam at either side of the bolt hole due to the minimum area at that point and the stress concentration associated with the hole in the beam. The next highest stress area is the point on the top of the beam where the beam ends meet the transition piece.

III HISTORY OF JET PUMP HOLD-DOWN BEAM FAILURES

In February of 1980 a jet pump hold-down beam failed at Dresden 3 resulting in a jet pump disassembly, which caused an orderly plant shutdown. Subsequent visual and ultrasonic inspections, conducted at the direction of General Electric (GE), disclosed that hold-down beams on other jet pumps at Dresden 3, Quad Cities 2 (March 15-16, 1980) and Pilgrim (March 28, 1980) contained cracks in the ligament zone at the center of the beams. Investigations determined that these cracks were caused by intergranular stress corrosion (IGSCC), which in the case of these jet pump beams, progressed very slowly over a period of years.

The NRC issued bulletin IEB-80-07 "BWR JET PUMP ASSEMBLY FAILURE" in April of 1980, that requested BWR-3 and BWR-4 facilities to perform inspections and to begin operability surveillances. This action arose from concern that the hold-down beam assemblies and subsequent jet pump function could degrade significantly during operation and that any jet pump disassembly could possibly reduce the margin of safety during postulated accidents.

In June of 1980, GE issued a Service Information Letter (SIL #330) "Jet Pump Beam Cracks" that highlighted the problem of beam cracking. As a result of the IEB-80-07 inspection requirements, several other plants discovered beam cracking. They included:

Plant	Type	#Beams
Dresden 2	BWR3	2
Dresden 3*	BWR3	6
Millstone 1	BWR3	5
Peach Bottom 3	BWR4	1
Pilgrim 1*	BWR3	3
Quad Cities 2*	BWR3	1
Vermont Yankee	BWR3	1

*Reported in IEB-80-07

The IEB-80-07 was closed out with a report NUREG/CR-3052 in October of 1984 with a summary of findings and resolution actions taken to date for BWR plants with operating licenses or construction permits. The issue of jet pump integrity was also closed as a generic issue in December of 1984 in NUREG-0933, "Issue-12: BWR Jet Pump Integrity". The safety significance of a jet pump failure will be discussed later, but it is worth mentioning that the jet pump integrity was an issue from the time that Quad Cities 2 had a jet pump disassembly due to improper installation in August of 1972.

More recently, in September of 1993, Grand Gulf experienced a jet pump disassembly due to a failure of a jet pump hold-down beam. The hold-down beam for jet pump #10 broke. After performing UT on the other jet pump beams one (#21) was determined to have IGSCC at the threaded hole region. The #10 beam was expected to have the break at this location; however, when the beam was retrieved from the annulus, it was found to have broken at one end and to have crack indications on the other end; with no cracks at the center region. This is a new type of failure mode and the first BWR6 to experience a beam failure. Grand Gulf decided to replace all of their beams during their ongoing refueling outage.

During UT inspection of the hold-down beams in October of 1993, the Clinton plant (another BWR6) determined that one of the beams (#7) had crack indications around the center hole region and it was replaced.

On November 22, 1993, Pennsylvania Power and Light (PP&L) notified the NRC that they would be replacing all of the jet pump beams at the Susquehanna 1 Station. This action was being taken after GE informed the licensee that they could not adequately predict, at this time, the crack initiation and crack growth rate of the beams, given the new failure mode of the Grand Gulf beam. The old method relied on predictable crack growth rates of IGSCC and cracks appearing at the center bolt hole region.

IV MATERIALS CONSIDERATIONS

Materials

Inconel X750 is a precipitation-hardenable, nickel-chromium alloy that was developed for corrosion and oxidation resistance up to 1300°F. This alloy has found application in gas turbines as rotor blades, wheels, bolts and other structural applications. It is also used in rocket-engines as thrust chambers. It is very similar to Inconel 600 with the addition of about 2.5 % titanium and would be expected to perform in manner similar to Inconel 600 in primary water.

The Inconel X750 was originally supplied for jet pump hold-down beams in the ASME Section II, SB-637 UNS N07750, Type 2 condition (equalized at 1625°F for 24 hours, aged at 1300°F for 20 hours to give a minimum tensile strength of 170 ksi and a minimum yield strength of 115 ksi). When it was discovered that this condition is susceptible to IGSCC in the late 1970's, the heat treatment was changed to SB-637 UNS N07750, Type 3 (anneal at 2000°F for 1 hour, age at 1300°F for 20 hours to give a minimum tensile strength of 170 ksi and a minimum yield strength of 100 ksi). Testing conducted by GE indicated that the new heat treatment would produce a jet pump hold-down beam that would not crack in the 40 year operational life of a reactor. As additional precautions, GE recommended that the preload be reduced from 30,000 inch-pounds to 25,000 inch-pounds and GE redesigned the hold-down beams to further reduce the likelihood of failure of the hold-down beams. Currently, there is a combination of hold-down beams in service, some with the old heat treatment and some with the new heat treatment, some with the old design and some with the new design. GE has been requested to supply a list that identifies the design and heat treatment for hold-down beams by licensee. The hold-down beams in service at Grand Gulf and Susquehanna had the reduced preload, but were the old design and the original or susceptible heat treatment. The replacement beams at Grand Gulf have the new design and the old heat treatment. Sufficient time was not available to procure hold-down beams with the new design and the new heat treatment. The replacement beams at Susquehanna are the new design and the new heat treatment.

Additional information will be necessary for the staff to confirm that the new design, the new heat treatment, and the reduced preload are sufficient to eliminate IGSCC of the hold-down beams.

Crack Initiation, Growth Evaluations

GE has previously estimated that a jet pump hold-down beam with the old heat treatment will have an average time for initiation of a crack of 8 years and an average of 2.5 years from initiation of a crack to failure of a hold-down beam. Hence, for an average hold-down beam, the useful life will be 10.5 years. The minimum estimated time for a crack to initiate would be 3.4 years and the minimum estimated propagation time would be 2 years. The average estimated initiation time for a hold-down beam with the new heat treatment was estimated to be more than 40 years. Because the time required to propagate a crack to failure is longer than an operating cycle, GE proposed that visual inspection of the hold-down beams during each outage would insure that there would not be any beam failures. These predictions were all based on the assumption that cracks would initiate at the bolt hole at the center of the jet pump hold-down beam. GE has revised this evaluation based on the failure at Grand Gulf Nuclear Station. It appears that cracks that initiate on the ends of the hold-down beam experience much higher crack growth rates and once crack growth starts, a crack can propagate to failure in less than one operating cycle.

The Grand Gulf licensee conducted a visual inspection of the hold-down beams during the last refueling outage and did not report any crack like indications on any of the jet pump hold-down beams. A record of the visual inspection is preserved on videotape, and has been reexamined with no evidence of the presence of cracks on the hold-down beam that failed in service. Videos of the broken beam indicated multiple IGSCC initiation sites on both ends of the beam. The end that did not fail had 2 initiation sites and the end that failed had 5 initiation sites. The 5 sites grew together to form a large crack that appeared to grow to a size that reduced the preload to the point that fatigue initiated. GE examined the fracture surface and indicated that stress corrosion cracking accounted for about 80 % of the fracture surface and fatigue accounted for the remaining 20 %. The staff intends to conduct a confirmatory analysis of the failed beam at the Brookhaven National Laboratory.

Inspection Methods

GE recommended that the following inservice inspection program be instituted in response to Bulletin 80-07. Plants with jet pump hold-down beams of the old design and old heat treatment should examine the hold-down beams every cycle for evidence of cracking. If evidence of cracking is identified visually, UT should be conducted to confirm the presence of cracking. The hold-down beam should be replaced with beams having the new heat treatment and new design or the old surveillance plan should be continued. The plants with hold-down beams with the old heat treatment should continue to do daily flow rate surveillance. Plants with hold-down beams with the new heat treatment should conduct the first visual examination of the hold-down beams after 5 years of operation and then every outage after the initial 5 years.

With the Grand Gulf failure, GE has provided the following comments on the inservice inspection program and the overall approach to IGSCC of jet pump hold-down beams in a letter to PP&L on November 20, 1993:

(1) The visual inspection may not be adequate to detect fine cracks at the ends of the hold-down beam

(2) The UT method developed to size cracks at the bolt hole of the hold-down beam is not able to detect cracks at the ends of the beam

(3) The cracks appear to propagate more rapidly at Grand Gulf and after a crack starts growing it could propagate-to-failure in less than one operating cycle

(4) Any plant that has 8 years of operating experience with hold-down beams heat treated using the old heat treatment should replace the hold-down beams before starting the next operating cycle

V PRELIMINARY SAFETY ASSESSMENT OF POTENTIAL CONSEQUENCES OF HOLD-DOWN BEAM FAILURE

The consequences of a jet pump hold-down beam failure depend on what happens to the jet pump assembly after the beam failure. Most probably, when the beam fails, the beam pieces will move around in the annulus region of the reactor vessel due to the water jet that will be formed from the drive flow from the recirculation riser and the reverse flow from the jet pump. For the events to date, the beams have been found in the annulus, not necessarily close to their respective jet pump. When the beam fails, the elbow piece (ram's head) raises off of its seating due to the hydraulic forces. This can allow the mixer throat assembly to be ejected due to the reverse flow through the jet pump and drive flow from the recirculation riser. Depending on the progression of the failure, this piece (weighing approximately 500 lbs.) can be ejected and possibly cause damage to other equipment in the annulus. In the case of Grand Gulf, there are indications that the mixer assembly struck the low pressure coolant injection piping above it, the reactor vessel wall, several steam separator stand-pipes, and a steam separator retainer bolt.

Although events to date have not resulted in sufficient damage to impact the operability of safety related systems or equipment, the potential for a loose jet pump assembly to cause such damage requires further study. Particularly, is there enough energy associated with mixer ejection to cause damage to the safety injection lines or other safety equipment such that they become inoperable?

The capability of reflooding the core to two-thirds height is dependent upon the structural integrity of the jet pumps. The two-thirds height of the core is at the same elevation that the suction flow enters the mixer throat (See Figure 6.). The elevation at which the mixer interfaces with the diffuser is at approximately 1/4 to 1/3 core height. If the structural system, including the beam holding a jet pump in place, fails, jet pump displacement and performance degradation could occur, resulting in an increased core flow area through the jet pump and a lower core flooding elevation. This could adversely affect the water level in the core during the reflood phase of a loss of coolant accident (LOCA) as well as the assumed blowdown flow during a LOCA. During a LOCA in a BWR, the core will eventually uncover, but this does not mean it will not be well cooled. Long term cooling relies on reflooding the reactor and maintaining a certain level of core coverage. The coverage assumed for most analyses is 2/3 height because this corresponds to the intact jet pump suction elevation. It has been licensing policy not to consider a broken jet pump as part of a design basis accident. This policy is similar to the decision not to consider multiple, independent breaks due to the low probability. In order for jet pump failure to become a core cooling problem, it has been shown that as many as 10-12 pumps must disassemble. The probability of a jet pump failure has been small, but it can not be precluded and could be increasing due to aging effects and new failure mechanisms.

The sequence of other events which must occur with a jet pump break for a core cooling problem to exist include: (From Memo for Victor Stello from R. B. Minogue, May, 1984 (Microfiche 25454, No. 227).

1. A break in the jet pumps must occur giving an equivalent area greater than 1 1/4 times the area of a complete off-set of the largest section of the jet pump (this is a welded location and not the smaller slip fit joint which has failed in operating BWRs and this equates to 10-12 jet pump disassembles at the slip fit). As Lahey shows in NUREG/CR-3376, two LPCI pumps will handle the flow of this equivalent leak.

2. A LOCA must also occur in the large recirculation piping (25-30") of a size equal to or greater that 1 1/4 times the equivalent area of a jet pump. This precludes the smaller recirculation riser piping. The recirculation line manifold is approximately similar in size to the jet pump opening and breakage here would be a single-sided break once the level in the downcomer decreased below the tops of the risers. Thus a break in the manifold would not be included in this sequence. Steam line breaks, feedwater line breaks, and other small piping breaks would also not be included because these lines are located above the core.

3. Failure of two independent core spray systems must occur or the operator must fail to recognize that the core is not reflooded and must terminate core spray. We view the termination of core spray by the operator to be very unlikely. A jet pump leak would be highly detectable because of failure of the diverse level instruments to show reflood. The emergency procedure guidelines require all emergency core cooling system (ECCS) to remain on until positive indication of reflood is obtained.

The probability of large pipe breaks combined with ECCS failures is small and to then combine that with multiple jet pump failures would reduce the probability further. The NRC previously viewed this as not a risk dominant accident sequence. The NRC also believed that consideration of broken jet pumps in licensing is not recommended in view of the expected small contribution to overall risk. The concerns of the jet pump integrity generic issue have not changed - only the mechanism for beam failure has changed. The staff has reviewed the scenario and believe that the findings of the 1984 evaluation remain valid. This view should be reviewed once an evaluation of the jet pump assembly missile consequence is completed.

The possibility of single or multiple jet pump beam failures as a result of short term increased hydraulic loads on the hold-down beams during the initial phases of a LOCA had been evaluated in the past. Given the new failure mechanism, this may have to be re-evaluated. The significance of such an event again depends on how many jet pump hold-down beams fail and how many jet pumps disassemble. The scenario would also depend on the operability of the safety injection systems. As long as core spray is available, the risk consequence is minimized. If a jet pump break were to occur, it would be detectable. Identification of jet pump failure following a LOCA would be readily detectable, because operator guidelines focus on reestablishing levels which would not occur if a major jet pump break occurred. The operator would therefore make use of other means (sprays) to cool the core.

There is the potential for loose parts from the broken beam and bolts in the retainer. In the events of the past; however, these pieces have been recovered in the annulus region, or have been small enough to be analyzed as not significant. The path for any parts to be able to obstruct flow from the top of the core is circuitous and it is highly improbable that pieces would make it through the steam dryers and separators (See Figure 7.). In order for pieces to enter the lower plenum region, the pieces would have to be sucked through another jet pump or travel down through the diffuser, against reverse flow, of the disassembled jet pump. For damage to occur, the pieces would have to become lodged in the lower portion of the fuel bundle or support piece assembly and block normal flow. This also is unlikely due to the low flow velocities in the lower plenum and to the lifting forces required to carry the piece to the fuel bundle flow entrance. It is believed that the detection and correction before substantial core damage due to any flow obstruction from a loose part can be relied on with a high probability.

It is unclear at this time what impact a disassembled jet pump would have on anticipated transients without scram (ATWS) scenarios. The condition should help with the power reduction from flow runbacks upon tripping the recirculation pumps due to the reduced jet pump flow capability. Natural circulation cooling flow could be enhanced by the larger flow area path to the lower plenum in the case of a disassembled pump or could be degraded if pieces block the flow path. Also, for plants that have standby liquid control system (SLCS) injection into the lower plenum, an evaluation should be performed to determine the impact that jet pump failure(s) would have on the flow path and shutdown capability of the boron injection. For plants with injection into the high pressure coolant injection (HPCI) spray line, there should be minimal impact; however, as was the case for LOCA consideration, the possibility for an ejected mixer assembly to cause damage to the safety injection lines needs to be evaluated. The missile damage potential and the ATWS response with failed jet pumps will be evaluated as part of the NRC Action Plan.

ABILITY TO DETECT FAILURE DURING NORMAL OPERATION

As a result of the Dresden 3 incident in February of 1980, the NRC issued IE Bulletin 80-07 "BWR Jet Pump Assembly Failure" and GE issued SIL No. 330 "Jet Pump Beam Cracks." Each document recommended jet pump flow surveillances that could be used to possibly predict a failure and definitely detect a failure during normal operation. For the earlier BWR 3 plants, based on evidence from Dresden, the surveillance could detect degradation trends in the differential pressure across the affected jet pump due to the reduction in hold-down beam preload and subsequent ram's head lifting allowing bypass leakage flow. This prediction capability was not anticipated to be as useful for BWRs using the later hold-down beam designs due to the change in installation preload and mechanical dimensions. For these plants, the prediction time of degraded jet pump performance before failure was expected to be less than 2 days. This was found to be true for the Grand Gulf case, in which the surveillance was performed with no indication of jet pump performance degradation just a few hours before the plant scrammed due to the jet pump failure.

A jet pump failure and/or disassembly will be readily detected. Besides the daily surveillance that will pick up the flow anomalies and determine the actual failed jet pump, there are several other indications that would indicate a problem. These include:

- Core power and electrical output will drop due to losses in core flow;
- Core plate differential pressure will drop due to decrease in core flow;
- The indicated loop flows will diverge with the unaffected loop's flow being increased due to the reverse flow through the failed jet pump;
- The affected loop's recirculation pump flow will increase for a given pump speed due to the decrease in flow resistance and will have a lower pump head pressure;
- Water level indications may oscillate near the affected jet pump and mismatches between regions in the annulus may also be detected, caused by the drive flow that bypasses the jet pump and the reverse flow of the disassembled jet pump; and
- Noise levels on the affected jet pump differential pressure readings will be lower due to the reverse flow in the jet pump.

Combinations of these indications were seen in this country at Dresden 3, Quad Cities 2, and Grand Gulf 1. The Quad Cities 2 incident in 1972 was not due to a cracked beam, but due to improper installation. The mixer did; however, become displaced and the plant indications showed the jet pump failure. At Dresden, the failure was noted in a similar fashion to Quad Cities. Upon review of the jet pump flow data from the weeks before the event, the degradation of the jet pump with leakage flow could be determined. At Grand Gulf, the plant scrammed after HPCI initiated due to water level anomalies caused by the jet pump failure. Upon startup, after the plant reached a power level where meaningful flow data could be taken, the operability surveillance and indications of water level oscillations led the licensee to determine that the jet pump had failed. Detection of a jet pump failure, due to any cause, is likely to occur due to the number of possible indicators.

OVERALL RISK

The risk implication was discussed briefly with the consideration of potential consequences. The risk from broken jet pumps is expected to be negligible compared to the overall risk. Jet pump hold-down beam failures could lead to core damage by two types of mechanisms. Frequency estimates for each of these mechanisms was considered in Generic Issue 12 of NUREG-0933 as follows:

LOCA Aggravation: A recirculation line break in addition to jet pump beam damage could prevent core reflooding. The two required events may not be independent; stresses resulting from a line-break LOCA could damage a weakened jet pump. However, for major core damage to occur, the jet pump damage must be severe enough to permit a coolant loss rate greater than the ECCS can replace, by opening a large flow area at a level well down in the core. For lack of better information, a conditional probability of 1 is conservatively assigned to LOCA aggravation (by a large enough hole being opened), given recirculation line break and given jet-pump hold-down beam breakage. Again, it is conservatively assumed that without periodic ultrasonic inspection and cautionary replacement of beams with incipient cracks, there is likely to be present a crack large enough to result in beam failure during a LOCA. As discussed, the probability of a cracked beam is assumed to be 1. Thus the contingent probability of LOCA aggravation by jet-pump hold-down beam failure, given recirculation line break, is 1 times 1 or 1. Based on WASH-1400 (Sec. III-6.4) and NUREG/CR-1659 (Vol. 4, pp 4-22), the estimated frequency of a recirculation line break is 10^{-4}/reactor year (RY).

For core damage to occur, the core spray must also fail. If, on the basis of WASH-1400 (p. II-5), one takes the probability of such failure as 10^{-3} (assuming core spray failure to be independent of jet-pump hold-down and diffuser failures), the estimated frequency (F) of core damage due to LOCA aggravation by jet pump beam failure is given by $F = (1.0)(10^{-4})(10^{-3})$/RY or 10^{-7}/RY.

Flow Maldistribution: Loose broken-off parts could obstruct flow in part of the core substantially aggravating maldistribution of flow due to loss of a jet pump. However, detection and correction before substantial core damage could occur can be relied on with a high probability. It is believed that the overall risk from the BWR jet pump problem can be estimated to a fair approximation in terms of the LOCA aggravation mechanism alone.

NUREG-0933 suggests that a reduction of the probability of at least one beam with cracking is possible if one accounts for flow monitoring, UT inspections, ant cautionary beam replacements. Given the new nature of the crack discovered at Grand Gulf and that the newer beams have a lower likelihood of discovering imminent failure during flow monitoring surveillances, such an improvement may no longer be a reasonable assumption. The IGSCC previously seen had predictable crack growths and could be detected by UT inspections on the beam. The new mode apparently has characteristics that are unquantified at this point in time and can not be detected with the current UT inspection procedures. Therefore, a reasonable basis for a bounding calculation is to continue using probabilities of 1.0 for a large enough hole being opened due to jet pump failures and for cracking to exist in at least one hold-down beam.

Another concern that could change the bases of these evaluations is if there is enough energy available when a mixer displaces to cause damage to the safety injection lines, which could invalidate the assumption of not having multiple independent failures. For example, the core spray failure is assumed to be independent of the jet pump failure, but if the ejected mixer assembly missile energy is large enough, there could be some dependent failure rate that must be included. The overall probability of such an event should remain low, but the consequence could be slightly increased due to the possible increase in the core spray failure probability caused by mixer assembly missile damage. The missile damage potential should also be considered for its impact on ATWS scenarios.

As stated previously, the risk due to jet pump failures was evaluated by the NRC in the past. At that time, it was determined that the risk from broken jet pumps was negligible compared to the overall risk. The sequence for core damage due to jet pump failure, combined with a large LOCA and core spray failure, was found to be a low probability event. This; however, did not include the possible dependent failure of the safety injection piping due to mixer assembly ejection. The impact of jet pump failures combined with an ATWS also needs further study, including missile damage potential and plant transient response. It is initially felt that this sequence will also be shown to be a negligible contribution to the overall risk. GE and PP&L have also stated that jet pump hold-down beam cracking or failure is not considered a safety significant event. **More information is required about the damage potential due to an ejected mixer assembly, the implications of jet pump failure(s) on ATWS scenarios, and the likelihood of beam failure due to transient hydraulic loads for the staff to reconfirm the "not significant" finding for the jet pump failure issue.**

VI <u>INDUSTRY ACTIONS/PLANS TO ADDRESS JET PUMP HOLD-DOWN BEAM ISSUES</u>

GE in revising the RICSIL on jet pump hold-down beams to include the Grand Gulf Nuclear Station experience. The RICSIL will provide information to each utility so that the utility can access the impact to decide on a course of action that best suits the utilities specific needs. GE 3 plants, as previously discussed, give advanced warning of a hold-down beam failure and are not included in the affected plants. Early warning capability indicating imminent beam failure (as by daily jet pump surveillance) is not effective with GE 4,5 and 6 beams. A list of the affected utilities is shown below:

GENERAL ELECTRIC PLANTS OF THE GE 4, GE 5, AND GE 6
TYPE WITH THEIR DATE OF FULL POWER OPERATION

Plant	Type	Full Power Operation
Vermont Yankee	GE 4	1972
Peach Bottom 2	GE 4	1974
Peach Bottom 3	GE 4	1974
Cooper	GE 4	1974
Duane Arnold	GE 4	1975
Edwin Hatch 1	GE 4	1975
Browns Ferry 2	GE 4	1975
James A. Fitzpatric	GE 4	1975
Brunswick 2	GE 4	1975
Brunswick 1	GE 4	1977
Edwin Hatch 2	GE 4	1979
Susquehanna 1	GE 4	1983
La Salle 1	GE 5	1984
La Salle 2	GE 5	1984
Washington Nuclear 2	GE 5	1984
Grand Gulf 1	GE 6	1985
Susquehanna 2	GE 4	1985
Hope Creek 1	GE 4	1986
Limerick 1	GE 4	1986
River Bend	GE 6	1986
Clinton	GE 6	1987
Perry 1	GE 6	1987
Fermi 2	GE 4	1988
Nine Mile Point 2	GE 4	1988
Limerick 2	GE 4	1990

GE has contacted Pennsylvania Power and Light (PP&L) about the Susquehanna Unit 1 jet pump hold-down beams because these beams will have been in service for more than 8 years during the next operation cycle. The licensee at PP&L has made the decision to replace all of the jet pump hold-down beams at Susquehanna Unit 1. The staff believes that this action is prudent because GE has not established the significance of the Grand Gulf failure.

The BWROG has not formulated an action plan to date. The BWROG has requested that GE provide the BWROG with a listing that indicates the actual operating hours for each GE 4, 5, and 6, the heat treatment (original or modified) for the hold-down beams, and the design for the beams (original or improved).

The NRC staff will meet with GE and the BWROG as soon as plans are more clearly formulated.

VII NRC ACTION PLAN

The staff's action plan is summarized below. The completion dates of the scheduled events in the action plan are not identified because it depends upon the responses from the BWR owners group, General Electric Company (GE) and the affected licensees. The staff would encourage the industry to take action in a timely manner to ensure safe operation of the affected BWRs.

(1) The staff will issue an Information Notice (IN) to alert the industry regarding the recent jet pump hold-down beam cracking experience at Grand Gulf. The action to issue an IN is already in progress.

(2) The staff plans to perform a confirmatory failure analysis at Brookhaven National Laboratory for root cause evaluation. The failure analysis will be performed on the sample piece taken from the broken jet pump hold-down beam recovered at Grand Gulf. The staff is negotiating with the licensee to have a sample piece for examination.

(3) The staff plans to meet with BWR owners group and GE to discuss their action plans in resolving this issue particularly in addressing the following staff concerns:

- In view of the Grand Gulf experience the effectiveness of visual and ultrasonic examinations in identifying the IGSCC on the jet pump hold-down beam as recommended in GE SIL may be questionable.

- What would be the safety consequences of broken pieces from the failed jet pump assembly damaging the safety related components which are critical to plant safe shutdown?

- Are there any unreviewed safety issues need to be addressed as a result of Grand Gulf experience?

- Root causes of the jet pump hold-down beam failure at Grand Gulf.

- Adequacy of GE recommended inspection schedule.

- Adequacy of GE recommended fixes (material heat treatment and reduction of preload) in their SIL 330.

- What are the possible affects that jet pump hold-down beam failures and pump disassembles have on the plant response during an ATWS and on the ability of the Boron injection to shutdown the reactor? This should include whether the ATWS could cause beam failure and also whether a beam failure could initiate an ATWS.

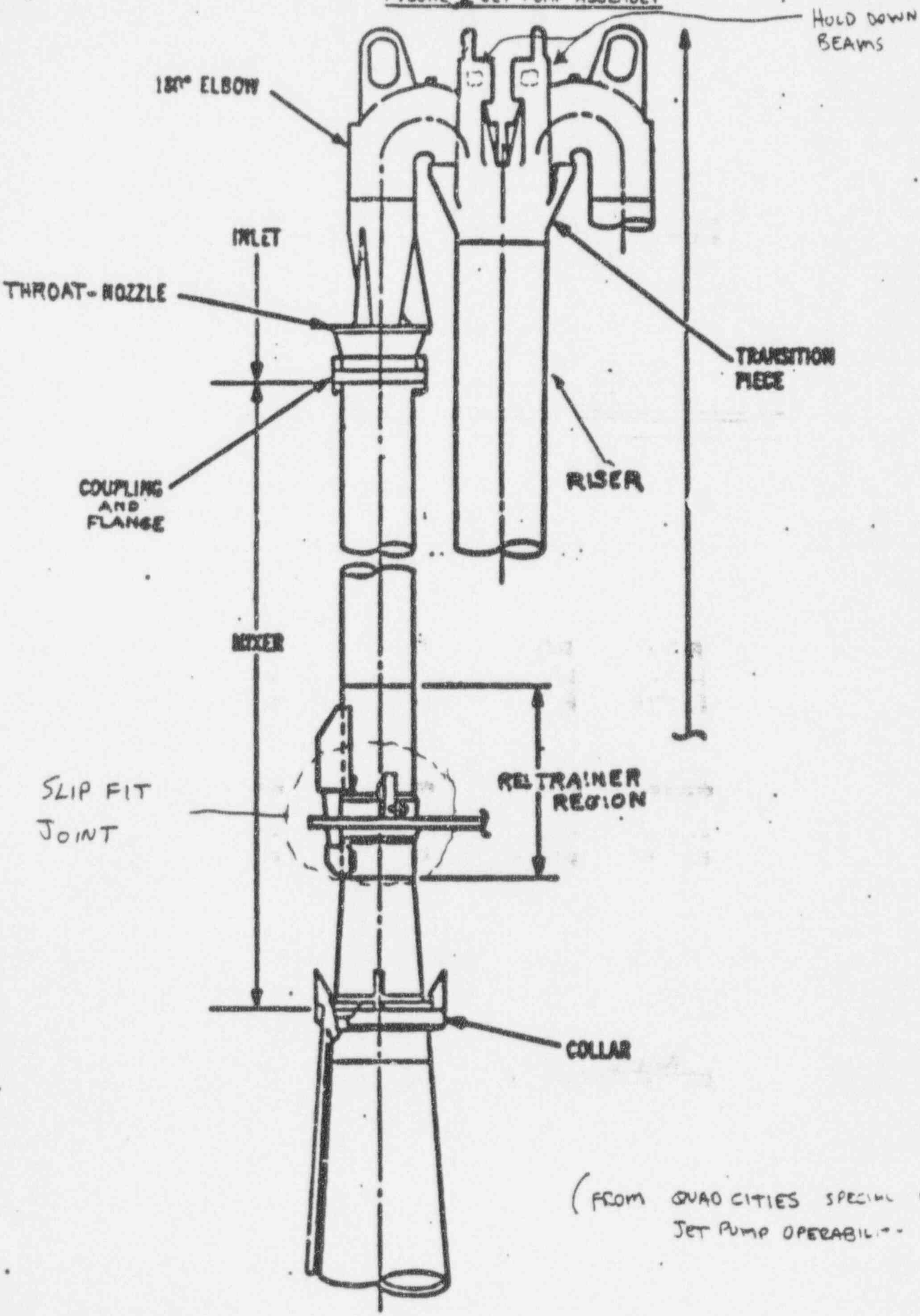
- Given the new location and mechanism of the beam cracking, is the likelihood of beam failure due to the LOCA transient hydraulic loads still remote?

(4) The staff will evaluate the safety consequences of this issue and determine the need of immediate regulatory action to ensure safe operation of affected BWRs.

(5) The BWR owners group has sponsored an on-going proactive program

with General Electric Company to evaluate the degradation of the BWR reactor vessel internals. The scope of the subject program includes ranking of internals that are susceptible to IGSCC, safety assessment of selected internal components, developing advanced ultrasonic inspection methods, repair and mitigation of IGSCC. The staff will continue to monitor this program and evaluate its effectiveness. Based on the recent field experiences the staff is in the process of identifying to the Commission that the degradation of BWR reactor vessel internals is an emerging technical issue.

FIGURE 1 JET PUMP ASSEMBLY



(FROM QUAD CITIES SPECIAL [illegible] #2 JET PUMP OPERABIL[illegible] [illegible]72)

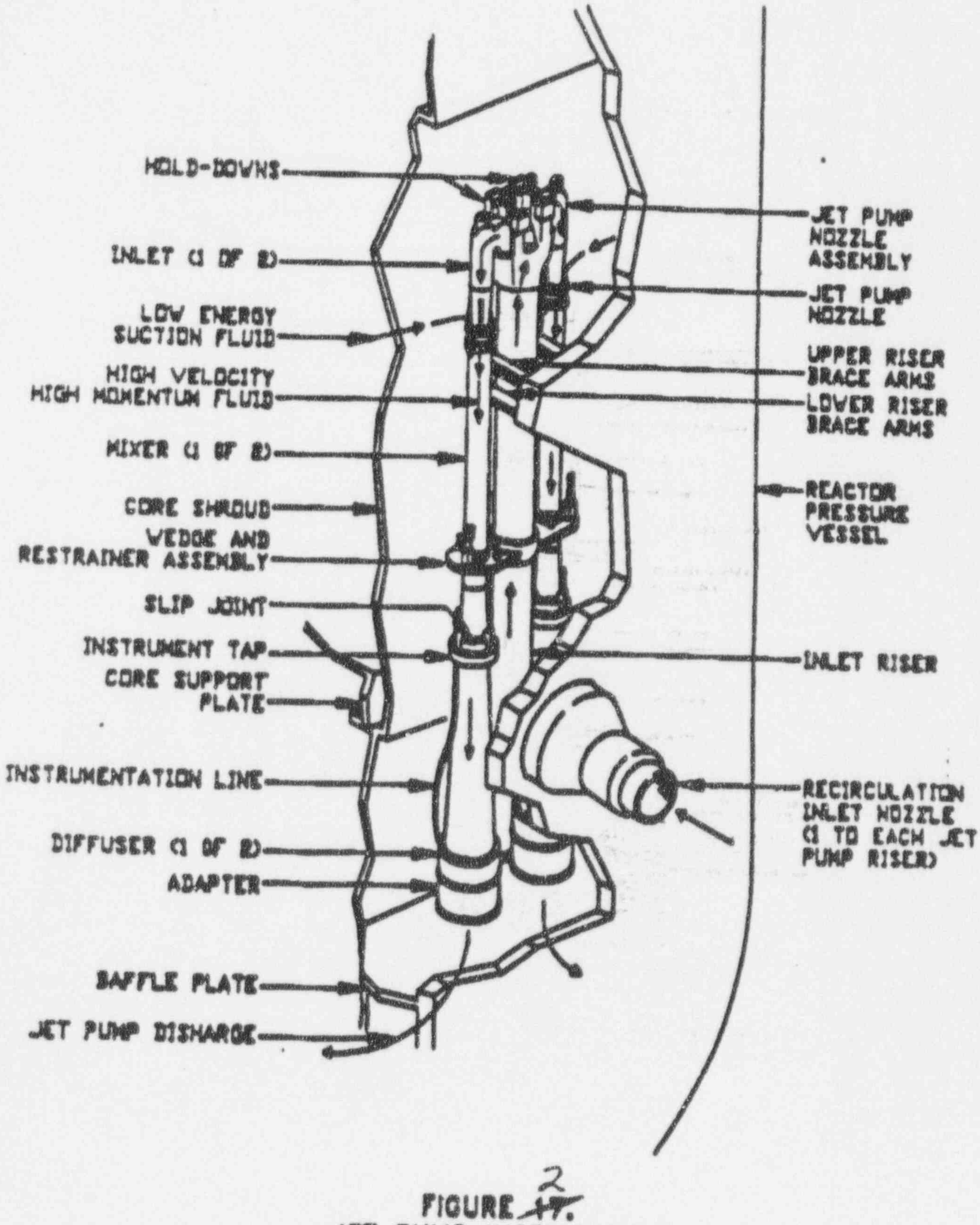
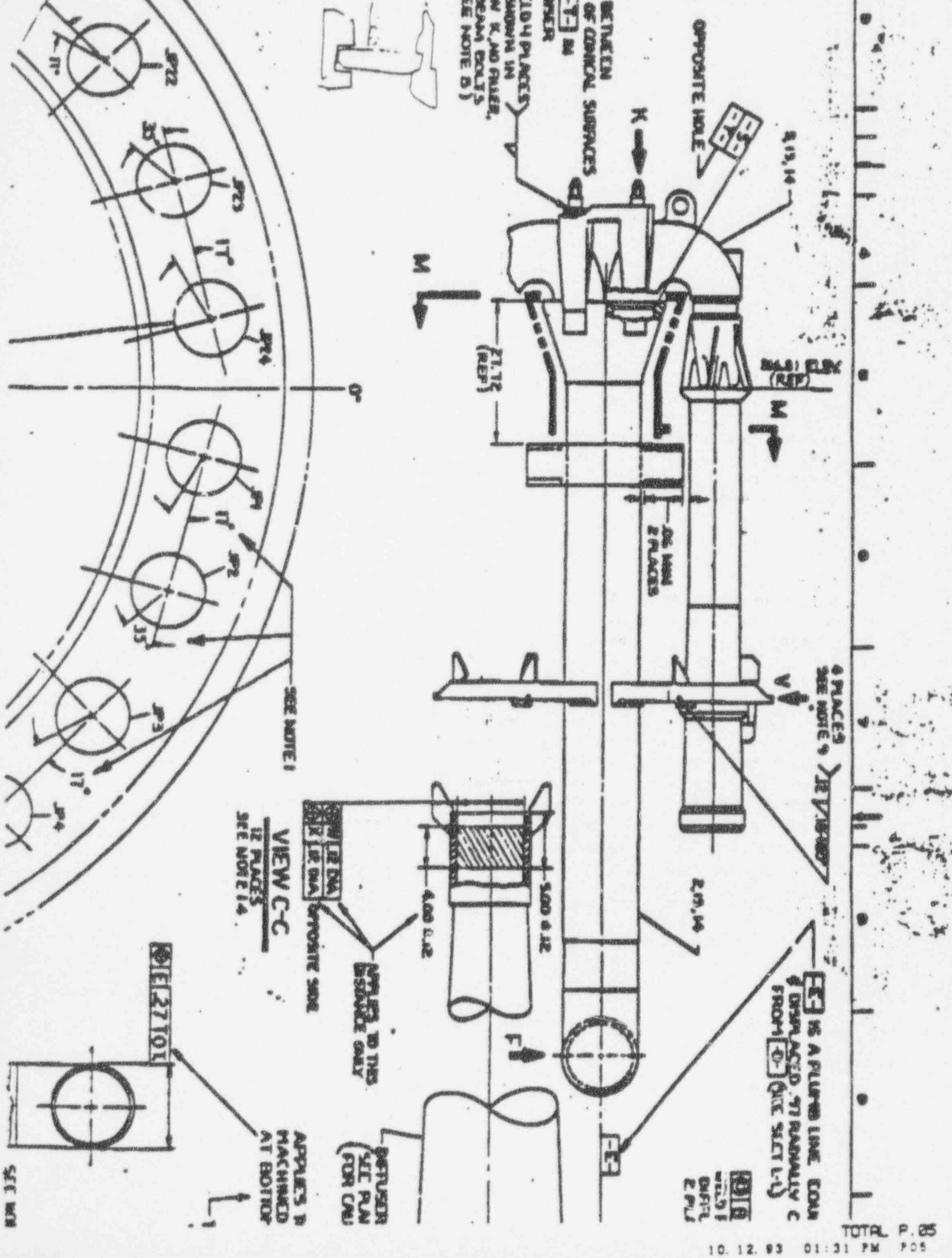


FIGURE ~~17.~~ 2
JET PUMP INSTALLATION

(From Grand Gulf)

FIGURE 3

(FROM GRAND GULF)



(FROM GE SIL No. 330)

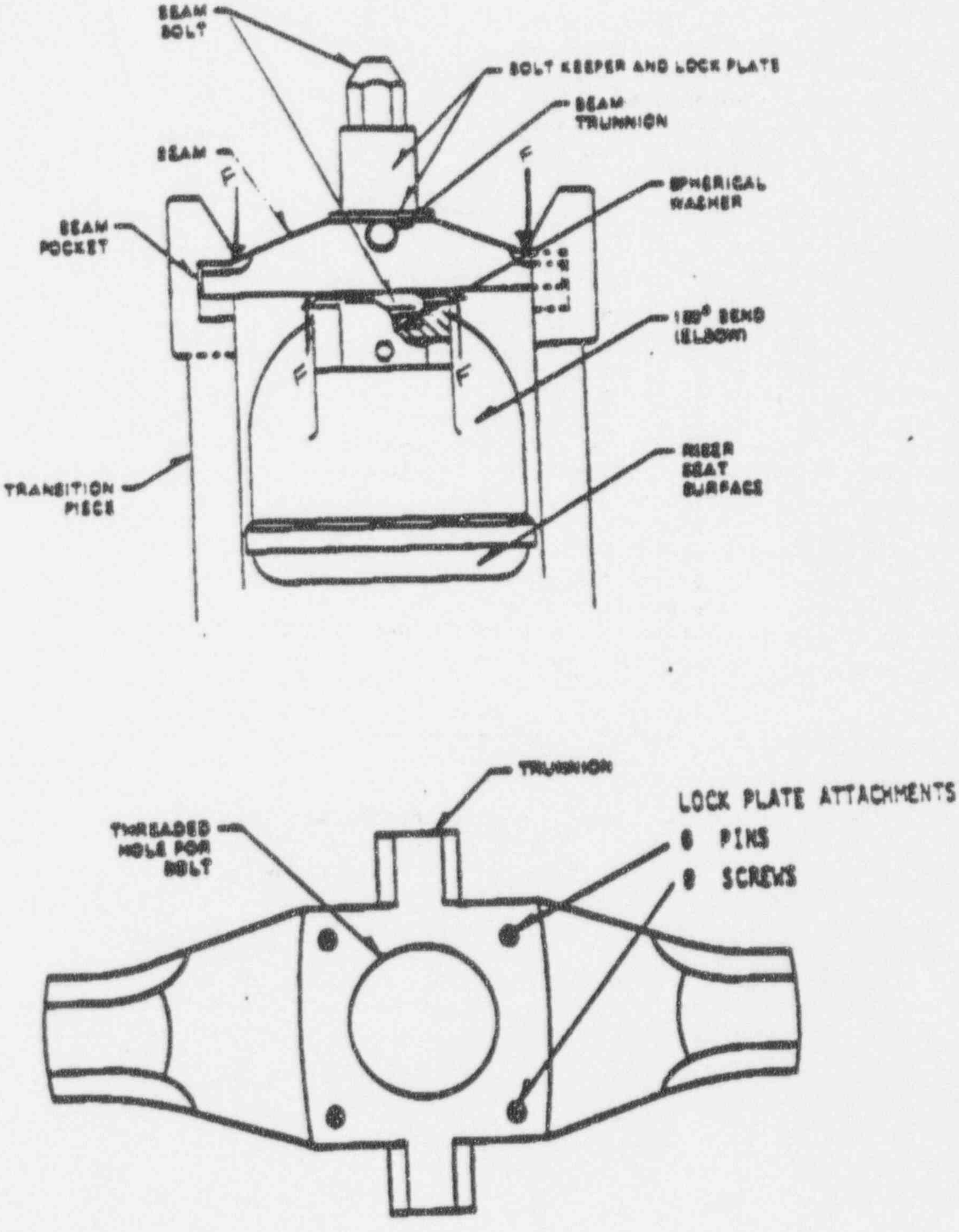
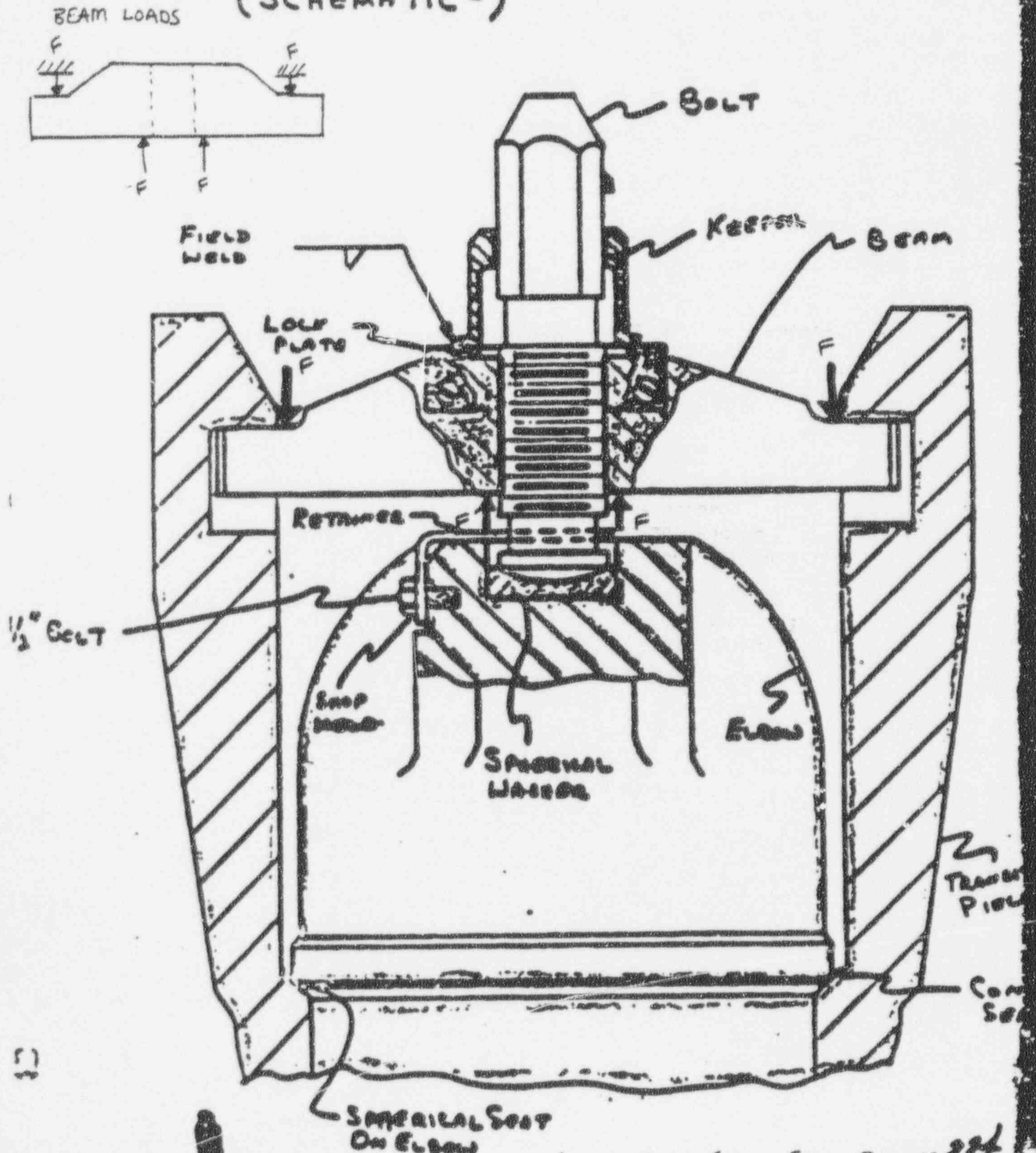


Figure ~~5~~ 4. BWR 4 Beam Assembly and Beam Top View

FIGURE 5

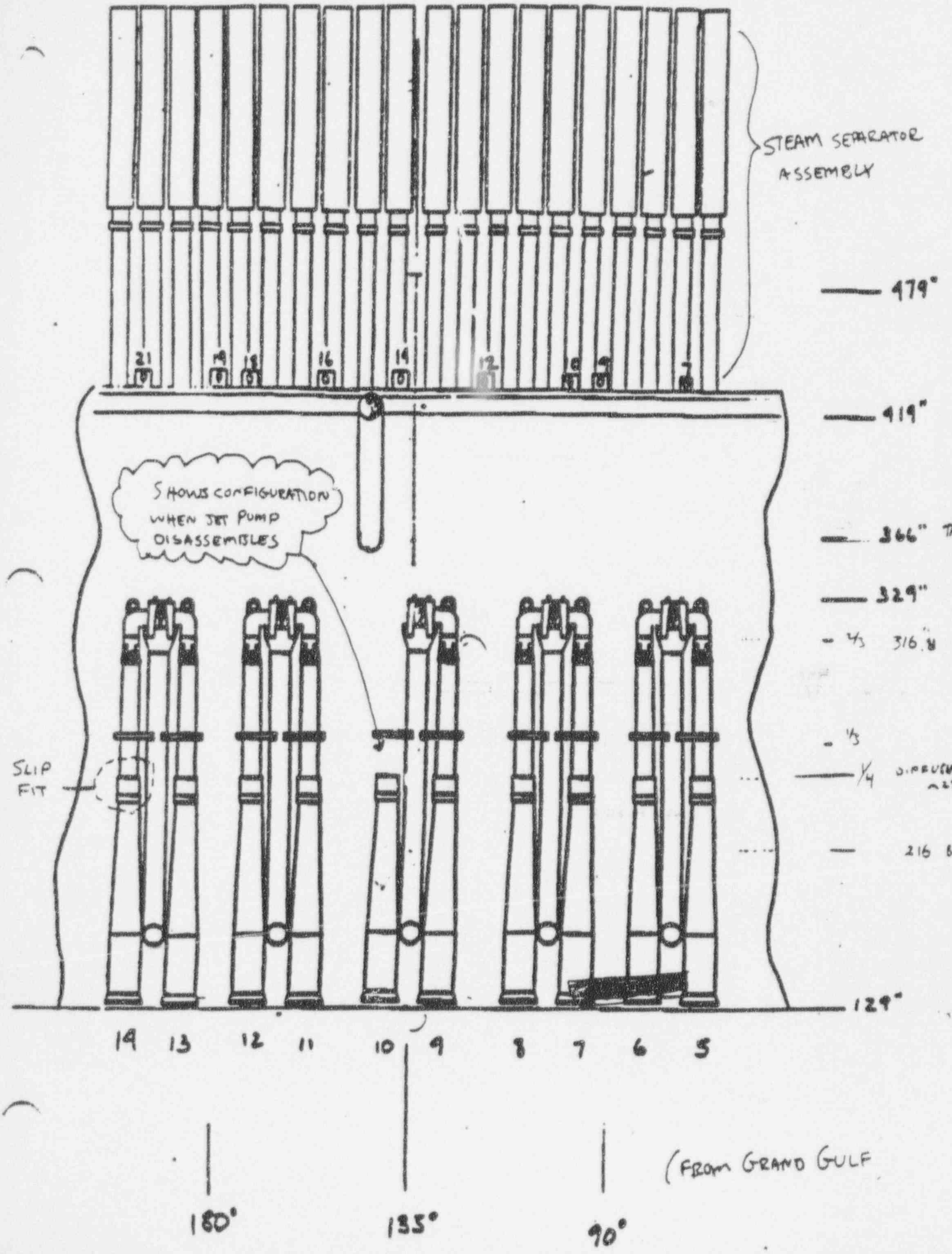
BEAM-BOLT ASSEMBLY

(SCHEMATIC-)



(FROM QUAD CITIES · SPECIAL REPORT #2 JET PUMP OPERABILITY, 1972)

FIGURE 6



(FROM GRAND GULF

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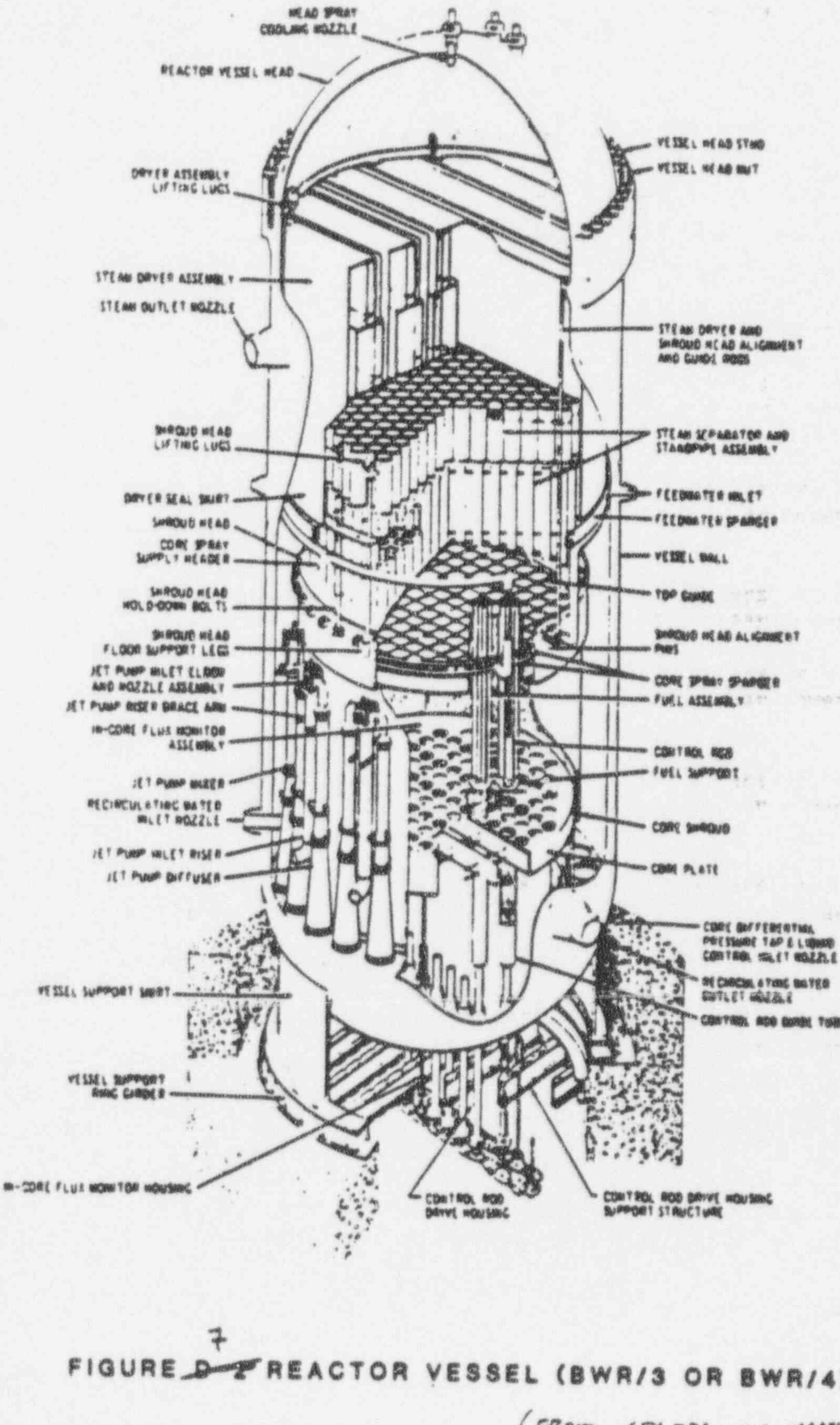

FIGURE ~~D-2~~ 7 REACTOR VESSEL (BWR/3 OR BWR/4)

(FROM GE/NRC TRAINING MANUAL)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, D.C. 20555

December 17, 1993

NRC INFORMATION NOTICE 93-101: JET PUMP HOLD-DOWN BEAM FAILURE

Addressees

All holders of operating licenses or construction permits for boiling-water reactors (BWRs).

Purpose

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice to alert addressees to a recent jet pump hold-down beam failure of a type not previously described by vendor guidance or by generic communications. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. However, suggestions contained in this information notice are not NRC requirements; therefore, no specific action or written response is required.

Background

On April 4, 1980, the NRC issued a bulletin, IEB 80-07, "BWR Jet Pump Assembly Failure," requesting that the owners of BWR-3 and BWR-4 plants perform visual and ultrasonic examinations of jet pump hold-down beams at the mid-length ligament sections bounding the beam bolt. This action resulted from a jet pump hold-down beam failure at Dresden Unit 3 and crack indications identified at other BWR-3 plants in early 1980. Observed cracks began at the bolt hole in the center of the jet pump hold-down beam. The bulletin also requested that licensees conduct jet pump operability surveillance on a daily basis and following unexpected changes in core flow indications, recirculation system flow indications, or an established power-core flow relationship. The nuclear steam supply system vendor, General Electric (GE), issued service information letters to owners of BWR plants on June 9, 1980, and in February 1981 providing guidance for recognizing jet pump problems using data gathered during plant operations. During implementation of the inspections prescribed in IEB 80-07, several other BWR-3 and BWR-4 plants reported discovery of beam cracking.

Description of Circumstances

On September 13, 1993, Grand Gulf power station (a BWR-6 plant) experienced an unplanned high-pressure core spray system initiation, due to a reactor low-water-level signal, that resulted in a reactor scram. Initially, the reasons for the water level anomalies detected in the "C" and "G" channels of the reactor water level instrumentation could not be determined. During restart from the reactor scram, the plant operations personnel discovered jet pump flow differential pressure anomalies. During the investigation of the problem, the plant experienced oscillating water level indications and jet pump flow readings characteristic of a displaced jet pump mixer section. These indications occurred at high recirculation flows in the reactor core (77 percent core flow). Following reactor shutdown and disassembly, the licensee found the mixer assembly for jet pump 10 had separated from the diffuser and relocated between jet pump 8 and jet pump 9. The hold-down beam for jet pump 10 had cracked and failed.

Discussion

The jet pump hold-down beam failure at the Grand Gulf power station in September 1993 is unlike previous failures in that the hold-down beam for jet pump 10 failed in the transition area between the main body of the beam and the beam end as shown in Attachment 1. There have not been any previous reports of failures in this location. One beam end failed completely, causing the beam to come out of the transition piece, removing the restraint on the jet pump elbow and leading to the disassembly of jet pump 10. There is one hold-down beam for each jet pump assembly. Visual examination of the failed beam showed a crack face covering more than 270° of the cross-section of the intact beam end; the other beam end had cracked in the same location and was missing. The cracks began in an area where a radius machining cut had been made in the forging and led to failure in a location of the beam with a cross-section smaller than the areas that had been affected in previous cases. GE concluded that the probable cause of failure was an intergranular stress corrosion crack that propagated over 80 percent of the fracture surface. Fatigue striations covered the remaining 20 percent of the surface. GE stated that the loss of preload as a result of the intergranular stress corrosion may have induced the fatigue failure.

The licensee conducted ultrasonic examinations on the other inservice jet pump beams and found indications on jet pump 8 and jet pump 21 at the bolt hole area in the center of the hold-down beams. This cracking was consistent with that described in bulletin IEB 80-07. The licensee replaced all the jet pump beams with spare beams available on site.

In October 1993, ultrasonic test inspection of the hold-down beams at the Clinton power plant (a BWR-6 plant) revealed that one of the beams had crack indications around the center of the bolt hole region and the beam was replaced. On November 22, 1993, Pennsylvania Power and Light Company notified the NRC that it would be replacing all of the jet pump beams at Susquehanna Unit 1 before restarting from their refueling outage. This action was being taken as a precautionary measure given the new failure mode identified at the Grand Gulf station. GE has made a recommendation to licensees that they replace their jet pump hold-down beams as soon as practical if (1) they have beams of the same design as Grand Gulf and (2) the beams will have an accumulated service of more than eight years at the next refueling outage.

The water level anomalies that occurred at Grand Gulf on September 13 and September 28, 1993 were apparently caused by the turbulent flow conditions in the vicinity of jet pump 10. The potential for level anomalies was not discussed in bulletin IEB 80-07.

7D4

The disassembly of a jet pump could result in an increased flow area through the jet pump and a lower core flooding elevation. This could adversely affect the water level in the core during the reflood phase of a LOCA as well as the assumed blowdown flow during a LOCA. Although events to date have not resulted in damage which affected the operability of safety-related systems or equipment, a loose jet pump assembly could potentially cause such damage.

The NRC staff will continue to evaluate information concerning the beam end failure mechanism as it becomes available and will follow the progress of any new inspection techniques and corrective actions that may be developed. The NRC staff expects to meet with the BWR Owners Group and GE to discuss their action plans as a part of the ongoing safety evaluation to determine the need for further regulatory action. Areas of discussion will include evaluations of damage potential due to a displaced jet pump, effects of a failed jet pump on plant ATWS response, and the potential for LOCA loads to induce hold-down beam failures.

This information notice requires no specific action or written response. If you have any questions about the information in this notice, please contact the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) Project Manager.

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Jonathan Witter, NRR
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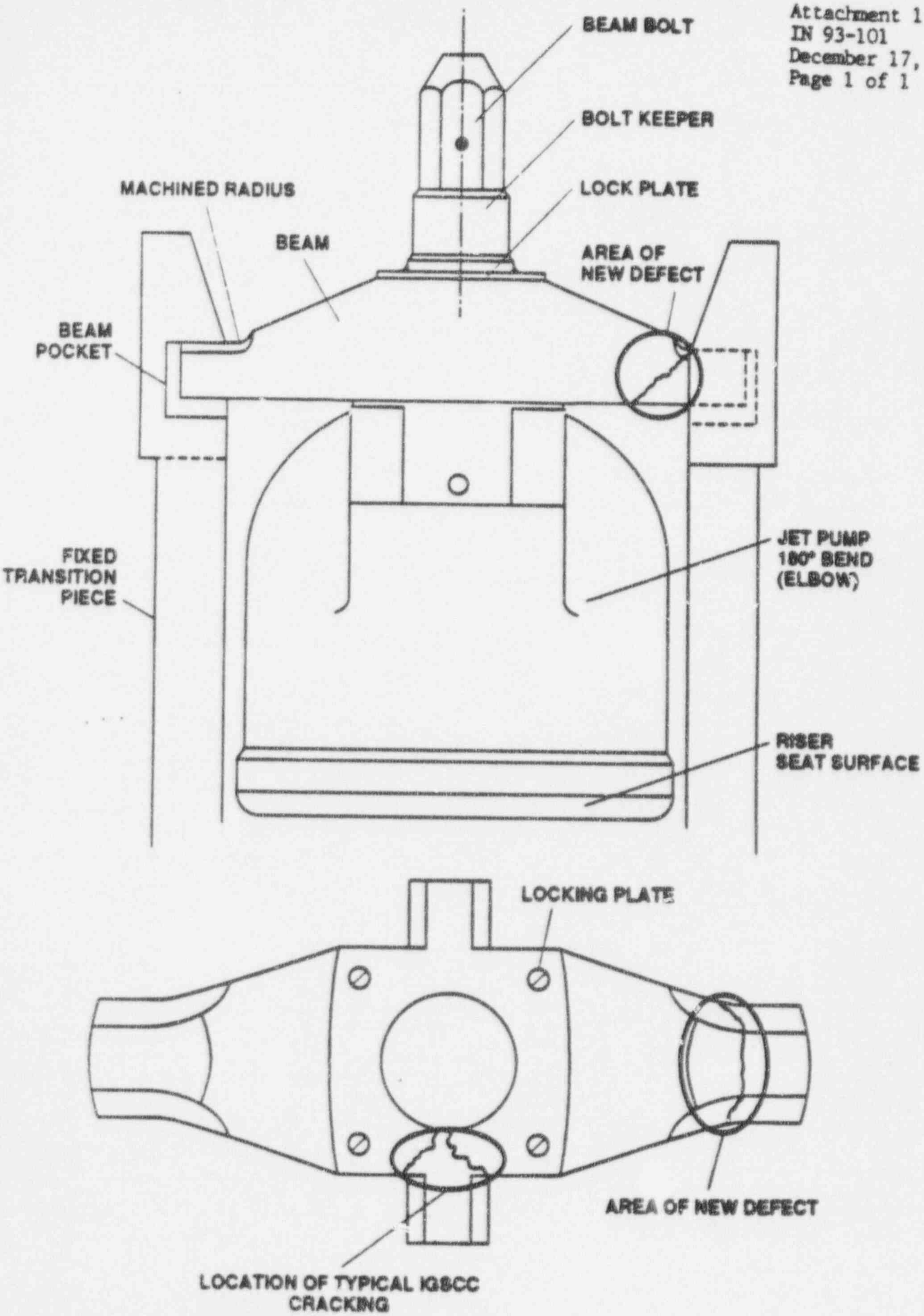
Attachments:
1. Figure - Jet Pump Beam Failure Location
2. List of Recently Issued NRC Information Notices



Jet Pump Beam Failure Location

LIST OF RECENTLY ISSUED
NRC INFORMATION NOTICES

Information Notice No.	Subject	Date of Issuance	Issued to
93-100	Reporting Requirements for Bankruptcy	12/22/93	All U.S. Nuclear Regulatory Commission licensees.
91-29, Supp. 2	Potential Deficiencies Found During Electrical Distribution System Functional Inspections	12/22/93	All holders of OLs or CPs for nuclear power reactors.
93-99	Undervoltage Relay and Thermal Overload Setpoint Problems	12/21/93	All holders of OLs and CPs for nuclear power reactors.
93-98	Motor Brakes on Valve Actuator Motors	12/20/93	All holders of OLs and CPs for nuclear power reactors.
93-97	Failures of Yokes Installed on Walworth Gate and Globe Valves	12/17/93	All holders of OLs or CPs for nuclear power reactors.
93-96	Improper Reset Causes Emergency Diesel Generator Failures	12/14/93	All holders of OLs or CPs for nuclear power reactors.
93-95	Storm-Related Loss of Offsite Power Events due to Salt Buildup on Switchyard Insulators	12/13/93	All holders of OLs or CPs for nuclear power reactors located close to a large body of salt water.
93-94	Unauthorized Forced Entry into the Protected Area at Three Mile Island Unit 1 on February 7, 1993	12/09/93	All holders of OLs or CPs for nuclear power reactors.
93-93	Inadequate Control of Reactor Coolant System Conditions During Shutdown	12/08/93	All holders of OLs or CPs for nuclear power reactors.
93-92	Plant Improvements to Mitigate Common Dependencies in Component Cooling Water Systems	12/07/93	All holders of OLs or CPs for nuclear power reactors.

OL = Operating License
CP = Construction Permit

GE Nuclear Energy

RICSIL Enclosure 3

Rapid Information Communication Services Information Letter

Jet pump beam cracking

RICSIL No 065

December 3, 1993

In SIL No. 330 Supplement 2, GE Nuclear Energy reported the loss of a jet pump beam–bolt assembly and inlet mixer at a GE BWR/6. GE has evaluated the beam–bolt design and conducted metallographic examinations of the failed beam at GE's Vallecitos Nuclear Center. The purpose of this RICSIL No. 065 is to provide current findings from those evaluations to GE BWR owners so that evaluations of jet pump beams relative to reliable reactor operation can be performed. Each owner then can assess plant impact and decide on a course of action that meets plant–specific needs.

Discussion

The failures reported in SIL No. 330 occurred in the middle section of the beams. Results of completed laboratory work show that the recent failure occurred in the transition to the arms at the ends of the beam. Initial laboratory examination results of the recent failure show that intergranular stress corrosion cracking (IGSCC) was the failure mechanism, also as reported in SIL 330. However, other factors that may have influenced crack initiation are still under investigation. These factors might isolate the failure to the GE BWR in which it occurred or to some other subset of the total population. Ultrasonic testing (UT) procedures currently in use do not address cracking in beam end locations. GE Nuclear is developing UT and other non–destructive examination (NDE) procedures to examine the beam ends.

The most significant new findings from the current evaluations are the following:

* Material and stress conditions are about the same at the beam middle section and end sections.
* Fracture mechanics evaluations indicate that crack growth to failure could occur in the beam ends in less than one 18–month operating cycle.

Failure of a jet pump beam–bolt assembly is not a reactor safety issue because existing jet pump operability surveillance procedures required by plant Technical Specifications detect beam failure.

Recommended interim action

It is not possible currently to determine by in–vessel examinations whether installed beams are crack free and suitable for continued service. Therefore, compensating actions are considered necessary.

The conservative short term recommendation is to replace all jet pump beams as soon as practical as a preventive maintenance action if they are in the same population as the failed beam described in SIL No. 330 Supplement 2. That population currently consists of all original–design beams (those with Equalized and Aged heat treatment) with accumulated service of more than eight years at the next refueling outage. The purpose of this recommendation is to avoid mid–cycle failures and possible damage to reactor internals. This recommendation applies to all GE BWR/3s, 4s, 5s and 6s.

If replacement is necessary, replace with GE part number 137C5238 G002 beam–bolt assemblies. These beams received High Temperature Anneal (HTA) heat treatment during manufacture and are less susceptible to IGSCC than the original Equalized and Aged beams. Original equipment beam–bolt assemblies—GE part number 137C5238 G001—are acceptable for use as interim replacements.

This recommendation does not apply to GE BWRs with GE part number 137C5238 *G002* beam–bolt assemblies installed (or with GE part number 137C5238 *G001* beam–bolt assemblies installed if those beam–bolt assemblies contained HTA beams). If completion of failure analyses and other studies currently underway produce any recommendations pertaining to these beams, GE Nuclear Energy will inform GE BWR owners.

As the failure investigation progresses, this interim recommendation may be changed. However, there currently is insufficient information and understanding of the failure described in SIL No. 330 Supplement 2 to support less conservative recommendations.

To receive additional information on this subject, please contact your local GE Nuclear Energy service representative.

This RICSIL pertains only to GE BWRs. The conditions under which GE Nuclear Energy issues RICSILs are stated in RICSIL No. 001 Revision 1, the provisions of which are incorporated into this SIL by reference.

Product reference

B13—Reactor System
B22—Nuclear Boiler System

Technical source

M. O. Lenz and J. H. Oates

Issued by

J G Moore

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