TMI-1 STEAM GENERATOR ADEQUACY OF TUBE PLUGGING AND STABILIZING REPAIR CRITERIA
TOPICAL REPORT - 010
REVISION 0 - VOLUME I

Project No: 120012

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Date: March 24, 1983

APPROVALS

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ABSTRACT

Purpose

The purpose is to demonstrate the adequacy of the tube plugging and stabilizing criteria to be used in repairing the TMI-1 steam generators after the 1981 tube cracking incident. These criteria, as a minimum, require a tube to be plugged if degraded per present Technical Specification limits and stabilized if there is a possibility of the tube becoming severed during power operations.

Results

The adequacy of the criteria is demonstrated by calculations and test results considering accident as well as normal operating tube loads.

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*Volume I includes 40 pages and Volume II includes 233 pages. All Tables and Figures listed above are included at the end of the appropriate sections and are not paginated.

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I. PURPOSE

The purpose of this report is to demonstrate the adequacy of the tube plugging and stabilizing criteria to be used in repairing the TMI-1 steam generators after the 1981 tube cracking incident.

The purpose of plugging is to prevent a leak through a degraded area of a tube from the primary to the secondary system or vice versa.

The purpose of stabilizing a tube (which also requires the tube be plugged) is (i) to help avoid having a tube with degraded areas become severed due to operation or if severed, (ii) to ensure the severed tube will not vibrate and damage an adjacent tube.

II. SUMMARY

Most of the tubes in the TMI-1 steam generators will be repaired satisfactorily by kinetic expansion within the upper tubesheet and the adequacy of this repair technique is presented in Reference 1. Other tubes which cannot be satisfactorily repaired by kinetic expansion will be plugged. Any tube which is considered to have a possibility of becoming severed anywhere between tubesheets will be stabilized. This report covers the criteria for determining which tubes must be plugged and stabilized or only plugged. The report also covers pertinent aspects of the design adequacy of the plugged/stabilized tubes themselves.

At TMI-1, stabilizer rod assemblies will be installed in certain tube spans to further ensure that these tube spans cannot sever and then vibrate and damage adjacent tubes. In addition, an extensive in service inspection program will be performed, as specified in Reference 2. This program will include ECT to confirm that operating tubes are not undergoing wear and wall thinning due to vibration of a severed span of an adjacent plugged tube. TMI-1 will thus provide substantial extra margin to ensure against this type of incident. Finally, with regard to the adequacy of the stabilized/plugged tube design, there has already been considerable actual operating experience obtained. For example, there is one tube in an operating once through steam generator (OTSG) in another plant which is known to be severed next to the upper tubesheet (highest cross flow span) and this tube has been stabilized and operating successfully since 1977.

The basic plugging/stabilizing criteria to be used in repair of the TMI-1 steam generators in 1982/1983 can be summarized as follows:

Plugging -- All tubes with defects not isolated by kinetic expansion, with greater than or equal to 40 percent through wall detectable indications by ECT will be plugged (same as existing criteria). Also, some additional tubes will be plugged for additional conservatism based on special ECT examination results.

Stabilizing -- All tubes that are considered to have a possibility of becoming severed between tubesheets will be stabilized. In addition for extra margin, other tubes will be stabilized on the basis of conservatively applied engineering judgment.

The adequacy of the plugging criteria as summarized above is discussed in Section III and the adequacy of the stabilizing criteria is discussed in Section IV. Basically, the overall plan regarding plugging and stabilizing includes extensive ECT to determine if a degraded area of a tube, not isolated by kinetic expansion repairs, exceeds conservative allowables. The term degraded as used herein refers to defect indications detected by ".540" standard differential ECT which are less than 40 percent through wall. If conservative allowables are exceeded, the tube will be plugged. In addition, if a degraded area of a tube were to become further degraded in service to the point that a defect is through wall, a leak would be detected and repaired per normal operating procedures. These degraded areas will be monitored at future ISI ECT examinations to reconfirm their adequacy to remain in service.

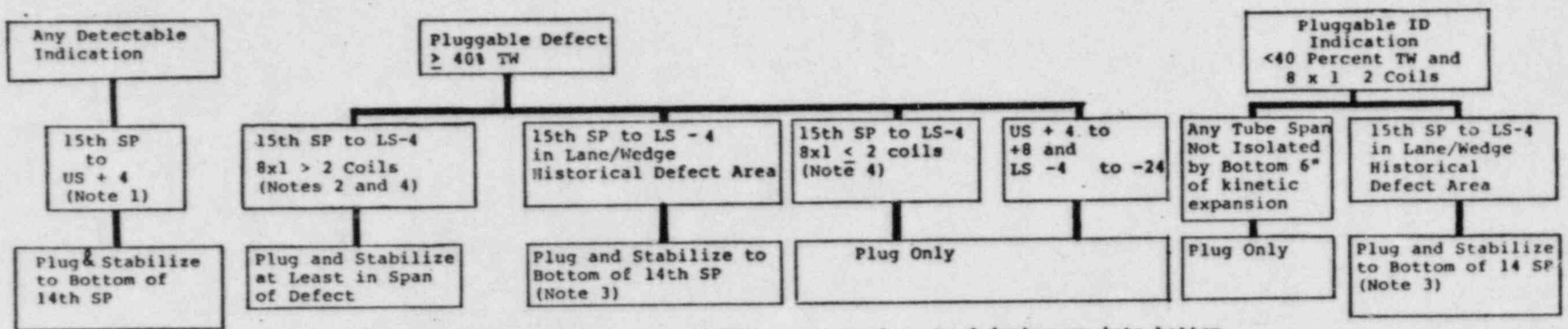
Next, an assessment is made from ECT for defective tubes to ensure that there is essentially no possibility of a tube becoming severed in any span between the upper and lower tubesheets. The term defective as used herein refers to any defect indications detected by the ".540" standard differential ECT which are greater than or equal to 40 percent through wall. If this is considered possible, then the tube will be stabilized so that even if severed, it cannot damage adjacent tubes. An extensive in service inspection program will be performed to ensure that operating tubes next to plugged tubes are not being damaged due to the potential unknown existence of an adjacent severed plugged tube. Finally, in addition to meeting all pertinent requirements with substantial margin, engineering judgment is conservatively applied to further ensure against undesirable events. For example, tubes located in certain regions of the steam generator where leaks have occurred in other plants, will be stabilized based on a more restrictive ECT acceptance criteria as discussed in the report.

Table II-A presents an overall outline of the basic tube plugging/stabilizing plan to be used during the 1982/1983 repair of the TMI-1 steam generators.

This report was prepared with input information obtained from GPU Nuclear, Babcock and Wilcox and MPR Associates.

TABLE II-A

<u>OUTLINE OF BASIC TUBE PLUGGING/STABILIZING PLAN</u>



1. Includes tube sections from bottom of 15th support plate to 4-inches up into bottom of upper tubesheet.
2. Includes tube section from bottom of 15th support plate to 4 inches down from the top of the lower tubesheet.
3. See Figure IV-1 for tubes in Lane/Wedge area.
4. 8xl is ECT probe with 8 absolute coils and 360° circumferential coverage.

III. PLUGGING CRITERIA

The plugging criteria to be used at TMI-1 is the same as existing criteria, i.e., plug if a defect in a tube (not isolated by kinetic expansion repair) equals or exceeds 40 percent through wall as detected by the ".540" standard differential ECT probe. For this criteria, the bottom six inches of the kinetic expansion repair joint must also be free of detectable defects 40 percent or more through wall or the tube must be plugged. In addition, tubes with detectable ECT indications on the inside diameter of the tube that are less than 40 percent through wall have also been reviewed and some of these tubes have been plugged based on an engineering evaluation. Specifically, if the special ECT probe (8 x 1 absolute) shows a detectable indication on three or more of its eight coils, then the tube will be plugged. Limits of detectability by the ECT are summarized in Figure III-2 and are covered in detail in Reference 8. To ensure that this criteria is adequate for the type of tube cracking as found at TMI-1 after the 1981 incident, the following evaluation was performed.

A. Characteristics of Cracks

The 1981 tube cracking incident at TMI-1 resulted in corrosion induced circumferential tube cracks originating from the inside diameter of the tube as shown in Figure III-1. As indicated in References 3 and 4, a large number of tube samples were removed from both steam generators and extensive metallurgical examinations were performed. Accordingly, these cracks can be characterized with considerable confidence.

The 1981 TMI-1 cracks have main characteristics as summarized in Table III-A and as discussed below.

1. The maximum crack in tube regions of interest had an arc length of 0.8 inch measured at the inside diameter of the tube and an arc length of 0.5 inch at the tube outside diameter. Thus, its average arc length was 0.65 inch. This crack as well as others was "thumbnail" in cross-sectional shape as shown in Figure III-1. The tube region of interest is considered herein to be any portion of the tube below 11 inches from the top of the upper tubesheet (UTS). The reason for this is that all

tubes at TMI-1 will either be kinetically repaired below this 11-inch elevation or they will be plugged. The reason that the maximum crack average arc length of .65 inches is of particular interest is that this size crack is almost structurally acceptable "as is" even if the tube were not plugged. However, the criteria in this report requires that tubes with such cracks would be plugged.

2. The maximum crack aspect ratio actually found in any of the TMI-1 tube samples is 8.9 for cases with less than 100 percent through wall penetration This crack aspect ratio is the crack arc length divided by through wall penetration. This ratio is considered to have been limited by the metallurgical and stress conditions within the tube as well as the corrosion process itself at TMI-1. This ratio is of interest because for any crack less than 100 percent through wall, the arc length is limited to a relatively small and acceptable value from a structural standpoint as will be discussed herein. As will be shown later in this report, this means that there is substantial margin for the 40 percent through wall plugging criteria used in repair of the generators.

B. Tube Loads

Because the TMI-1 1981 cracks in the tube regions of interest are circumferential, the pressure load capability of the tube is not significantly affected by these cracks. Specifically, this is a straight tube type steam generator and the tubes are fixed at each end within tubesheets; therefore, thermal and mechanical loads are the main loads of interest herein. The loads of interest regarding plugging are summarized in Table III-B.

1. Axial Loads

The design basis loads in Table III-B, are axial tube loads of 3140 pounds tension for main steam line break, 1107 pounds tension for shutdown and 775 pounds compression for startup. See References 5 and 9.

The values of these design basis tube axial loads are considered to be conservative for TMI-1 because of the assumptions as stated in Reference 5. For example, Reference 5 assumes a double-ended main steam line break of 36-inch diameter pipes and TMI-1 only has 24-inch steam pipes and these pipes are arranged so that an effective double-ended break cannot occur.

The design basis loads and the vibration stresses in Table III-B for normal operating conditions are directly applicable for tubes which are not plugged. However, and as will be discussed as follows, these loads and stresses are also applicable in the evaluations herein for plugged tubes as well.

The main purpose of the stabilizing criteria for plugged tubes is to ensure that any unstabilized plugged tube will not become parted. In this report, the loads of concern for a plugged tube are the ones which put the tubes in axial tension in defective areas and which thereby tend to part the tube. Further, only the normal operating condition loads are of concern regarding stabilizing of plugged tubes. Accident loads are not a concern since there is no problem if a plugged tube were to become severed during an accident, e.g., a main steam line break, because there would not be enough time for a severed plugged tube to cause any significant damage (wear) to an adjacent tube. See Section IV for further discussions of this issue.

The maximum tensile tube load during normal operations is 1107 pounds for both a plugged as well as an unplugged tube. This load occurs due to a mismatch in tube versus steam generator shell temperature about two hours into a design basis (100°F per hour) cooldown transient. During normal steady-state operation at power, a plugged tube will operate at a lower average temperature than an unplugged tube, and the axial load will therefore be more tensile for a plugged tube. However, as indicated in Section VIII-I the magnitude of the plugged tube load during steady-state operation is less than for a design basis cooldown transient. Therefore, the maximum design basis

tensile load for a plugged tube is still the 1107-pound value for the cooldown transient as discussed below.

During a cooldown transient, the axial load is essentially the same for both types of tubes because the temperatures of plugged and non-plugged tubes are essentially the same even after only a few minutes elapsed time into this transient. The reason for this is that the temperature of the reactor coolant system and the secondary side temperature (steam temperature after saturation is reached during the cooldown transient) are essentially the same after a few minutes into a cooldown transient. These temperatures are illustrated in Figure 5-8 of Reference 5. Since the primary and secondary side temperatures are essentially the same at time periods of interest (about two hours into the cooldown transient when tube loads are maximum), then the temperature of a non-plugged tube will be essentially the same as for a plugged tube. Accordingly, the maximum tube axial load for a plugged tube as well as a non-plugged tube will be essentially the same, i.e., a design basis value of 1107 pounds will be used in both cases.

2. Flow Induced Vibration Loads

The flow induced vibration (FIV) tube stress of ±540 psi in Table III-B was obtained from Reference 11. This stress is based on the maximum instrumentation test results for both TMI-2 and Oconee 2 tests at essentially full power on actual steam generators as indicated in References 6 and 7. This FIV stress of ±540 psi (obtained from measurements in the 16th span) is considered representative of expected stress levels in the worst-case locations in TMI-1, i.e., in the 16th tube span (highest cross flow) and just below the upper tubesheet (UTS). Higher FIV tube stresses were measured at this same location in both Oconee 2 and TMI-2 at lower power ranges of about 40 to 80 percent where water level oscillations also become greater as indicated by increasing steam pressure oscillations.

These higher FIV stress levels are not considered applicable for TMI-1. This is because the operation of TMI-1 has been and will continue to be

limited by administrative control insofar as practical to minimize the time pericds of operation at these lower power levels where steam generator water level oscillations occur. These water level oscillations can be monitored by monitoring of steam pressure fluctuations at about 0.25 Hertz for each generator. Further, with the present steam generator downcomer feedwater orifice settings ("A" generator is about 25 percent open and "B" about 25 percent) the magnitude of the water level oscillations in TMI-1 is only about 50 percent of the maximum values which have been measured in other plants. Finally, since TMI-1 has not, in the past, had tube failures due to fatigue, we conclude that the past practice of minimizing time of operation at lower power ranges (together with the present downcomer orifice setting) is sufficient to prevent fatigue of the tubes.

3. <u>Effects of Combined Axial and FIV Tube Loads</u>

Steam generator tube failures have occurred in another OTSG in 1977 due to fatigue, probably after crack initiation due to corrosion. Section VIII-A of this report presents calculations which correspond with these tube fatigue failures. In essence, on the basis of these calculations, the following is indicated:

- If the superheat zone of a tube is wetted on the secondary side due to water level oscillations, its axial tensile stress due to the water level oscillations and the normal operating axial loads is about 4000 psi even at low power levels about 40 percent.

- FIV stresses (about ±4000 psi) have been measured during low power ranges about 40 and 55 percent at TMI-2 and Oconee 2 respectively.

- These FIV stresses combined with the above axial stress result in a cyclic stress about 0 to 8000 psi tension which we calculate will propagate certain sizes of cracks (about 0.015 to 0.025 inch deep).

- Small cracks approaching 0.015 inch deep have been found apparently due primarily to corrosion.

Accordingly, this 1977 OTSG tube fatigue failure can be reasonably explained by the calculations in Section VIII-A.

These same type calculations (in Section VIII) show that the corrosion cracks in unplugged tubes in TMI-1 will not propagate and this is basically because FIV stresses and axial tube stresses will be substantially lower in TMI-1 because of the planned administrative limits (see Reference 10) on operation of the plant and because of the existing steam generator downcomer orifice settings.

C. Tube Load Capability versus Extent of Cracking

The capability of a tube to withstand the pertinent loads in Table III-B is calculated in Sections VIII-B, C and D. These calculations include ASME fatigue type calculations using a fatigue strength reduction factor of 5 and fracture mechanics crack growth type calculations as well. As discussed in Section VIII, the results of the calculations agree well; however, for conservatism, worst-case results are used to evaluate the criteria in this report.

The pertinent calculations are based on the conservative assumption that the tube crack is in a worst-case tube location, i.e., within the 16th tube span where the highest cross flow exists. By comparison, tubes which have cracks located up within the upper tubesheet can withstand considerably greater loads; this is because of the support and constraint provided to the tube by the hole in the upper tubesheet. Since most of the tube cracks at TMI-1 were located up within the upper tubesheet, most of the tubes, if cracked, would have substantially greater load capability than indicated throughout this report.

The results of these calculations are plotted in Figures III-2 and III-3 as a function of the assumed crack percent through wall penetration versus the arc length of the crack. Specifically, these figures show the sizes of cracks which would not be acceptable, i.e., these sizes are calculated to sever the tube if the appropriate number of load cycles in Table III-B were applied.

Figure III-2 compares the maximum acceptable crack sizes with the limits of detectability for the .540 inch diameter ECT probe at gain (60) in a worst-case location (within the tubesheet) as well as in other locations (between tubesheets). As shown, there is considerable margin between the capability to detect a crack and the need to detect a crack. For example, for a 100 percent through wall crack, ECT has the capability of detecting a crack about 20 percent of the arc length necessary to cause tube failure. This indicates that ECT sensitivity is more than sufficient to detect any crack size of concern. Further, the 8 x 1 absolute ECT probe has been used to define the maximum arc length of the detected defects for use in making plugging and stabilizing decisions. Accordingly, ECT provides a conservative means to determine which tubes should be stabilized and/or plugged as discussed throughout this report.

In addition to ECT, a substantial amount of information has been obtained from metallurgical examinations of cracked tubes removed from the TMI-1 steam generators. This information further ensures that application of the plugging/stabilizing criteria based on ECT will be conservative. For example, the 1981 cracks in TMI-1 are "thumbnail" in shape, as shown in Figure III-1. The importance of this feature is that even if the percent through wall penetration of one of these cracks is actually substantially greater than indicated from ECT, there is still ample margin. This can be seen from Figure III-3 which compares the maximum acceptable crack sizes with the maximum expected crack sizes, based on the configuration of crack growth in radial versus circumferential directions as determined from metallurgical examinations of actual TMI-1 tube samples. For example, even if a crack was actually 95 percent through wall and if it were inadvertently determined to be less than 40 percent through wall, by ECT, and not plugged, there would still be substantial margin regarding allowed versus expected crack size.

D. Evaluation of Tube Plugging Criteria

As stated before, all tubes with detectable defects (greater than or equal to 40 percent through wall by ECT) in tube locations not isolated by kinetic expansion repairs will be plugged. Accordingly, any tube defect above the kinetic expansion repair joint

(bottom six inches of the expanded tube section) does not require plugging because the tube is considered satisfactorily repaired, i.e., these defects are isolated by the kinetic expansion. The effect of applying this plugging criteria for tube defects of the 1981 TMI-1 type is shown in Figure III-3 to produce very conservative results. In essence, application of the 40 percent through wall criteria means that only very small ID defects (less than about 0.15 inch average arc length) would be permissible without requiring the tube to be plugged. Also, margins are substantial to cover any uncertainties involved. Accordingly, the plugging criteria evaluated herein is considered adequate. Finally, it is considered highly desirable to leave some tubes in service with these small ID ECT indications (less than 40 percent through wall) so that these indications can be monitored by ECT for any possible future growth.

Table III-A

TMI-1 STEAM GENERATOR TUBE DEFECT CHARACTERISTICS FROM 1981 CRACKING INCIDENT*

1.	Average Arc Length of Maximum Crack	0.65-inch
2.	Maximum Crack Aspect Ratio	8.9

$$\text{Aspect Ratio is: } \frac{\text{Arc Length}}{\text{Through Wall Penetration}}$$

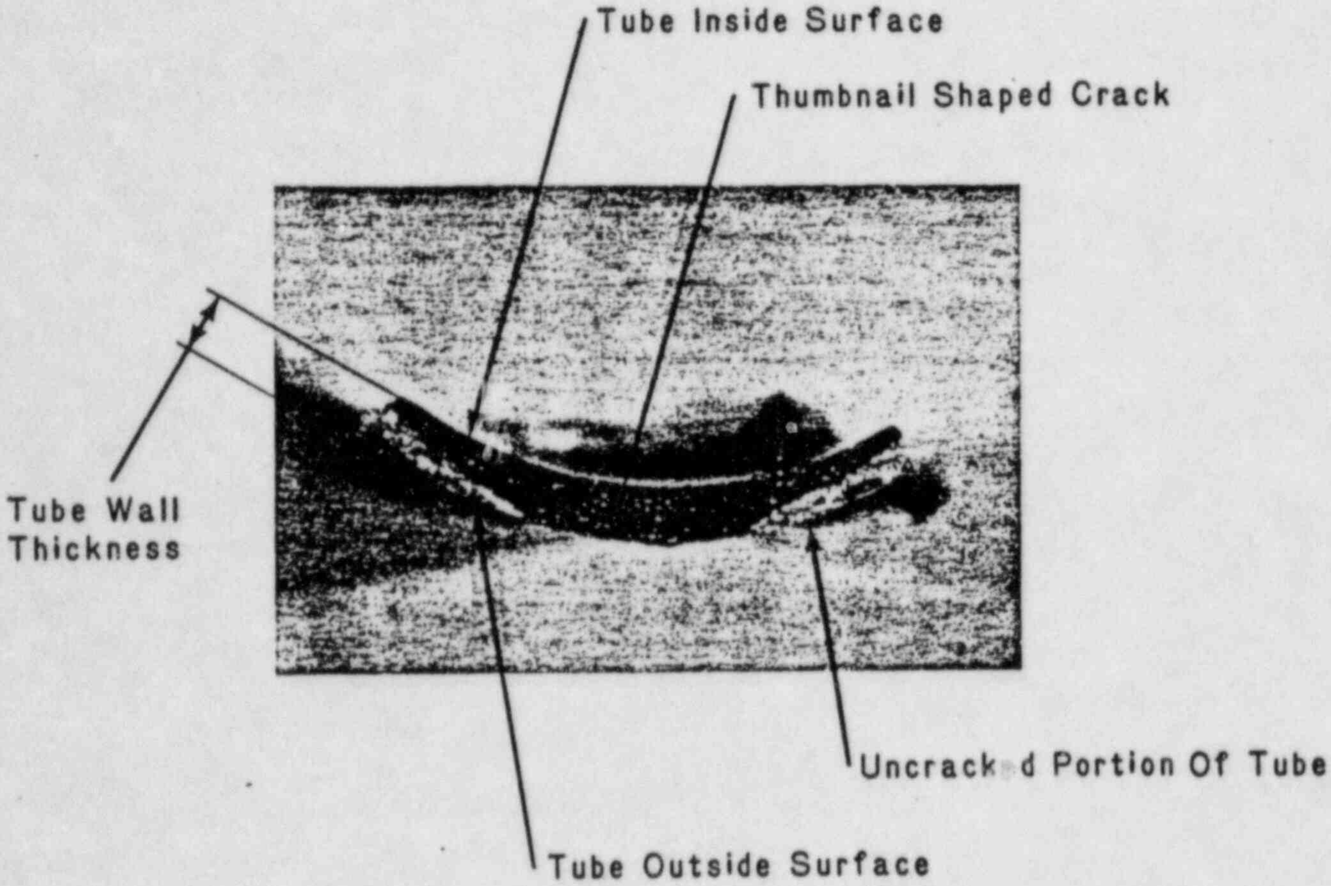
* These characteristics were determined for tube cracks located in the pertinent regions of interest, i.e., below the elevation of the top of the kinetic repair qualification joint. This elevation is 11 inches down from the top of the upper tubesheet for the 17-inch long kinetic expansions.

Table III-B

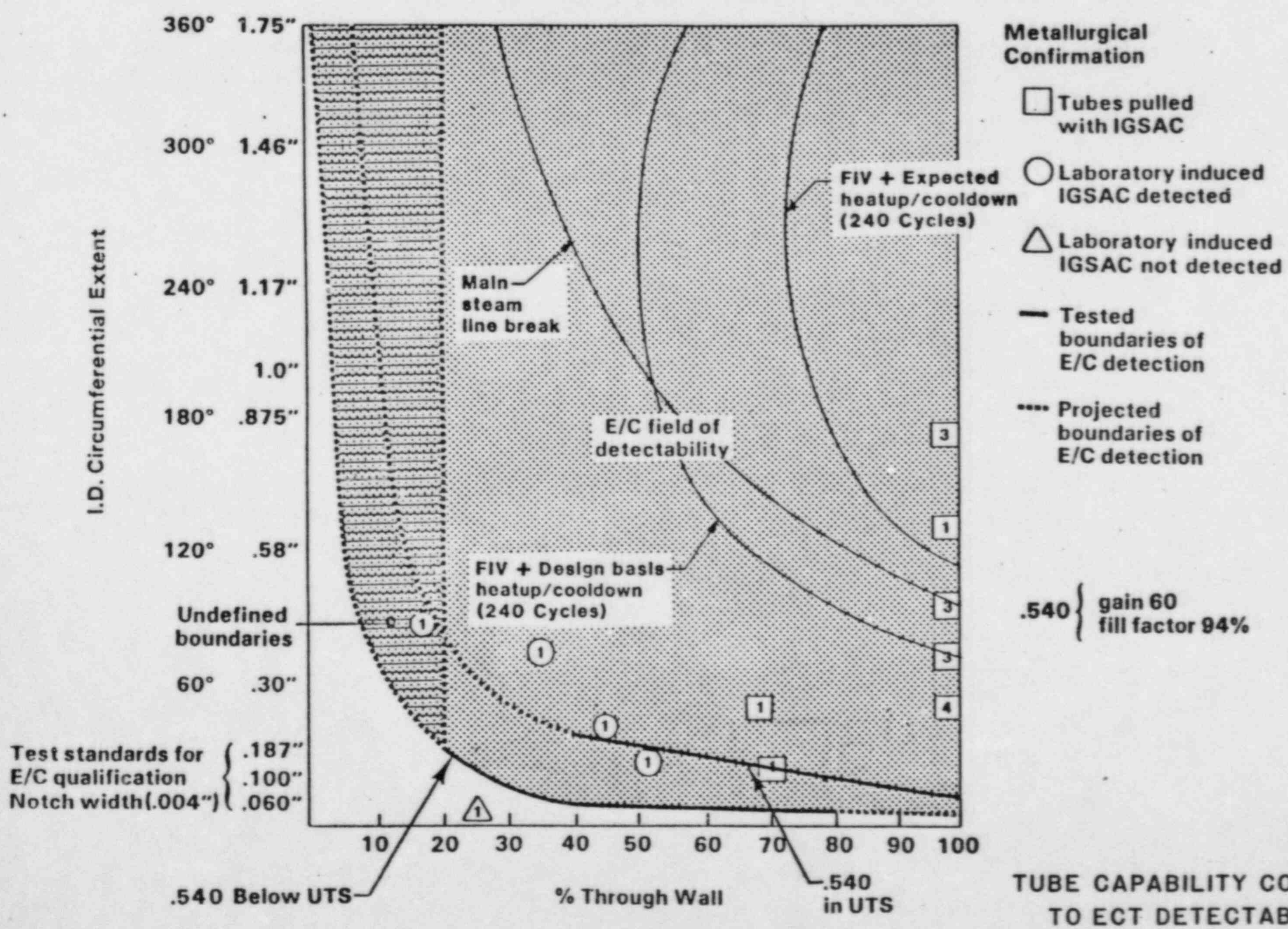
TMI-1 DESIGN BASIS AND EXPECTED TUBE LOADS* FOR 1981 TUBE CRACKS

Condition	Type of Load	Magnitude	Number of Cycles
Accident - Design Basis Main Steam Line Break	Thermal-axial	3140-lb tension	1
Normal - Design Basis Startup	Thermal-axial	775-lb compression	240
Normal - Design Basis Shutdown	Thermal-axial	1107-lb tension	240
Normal - Expected Startup	Thermal-axial	388-lb compression	240
Normal - Expected Shutdown	Thermal-axial	554-lb tension	240
Flow Induced Vibration at 100 Percent Power	Worst location bending stress	±540 psi	$> 10^6$

* See References 5 , 9 and 11.

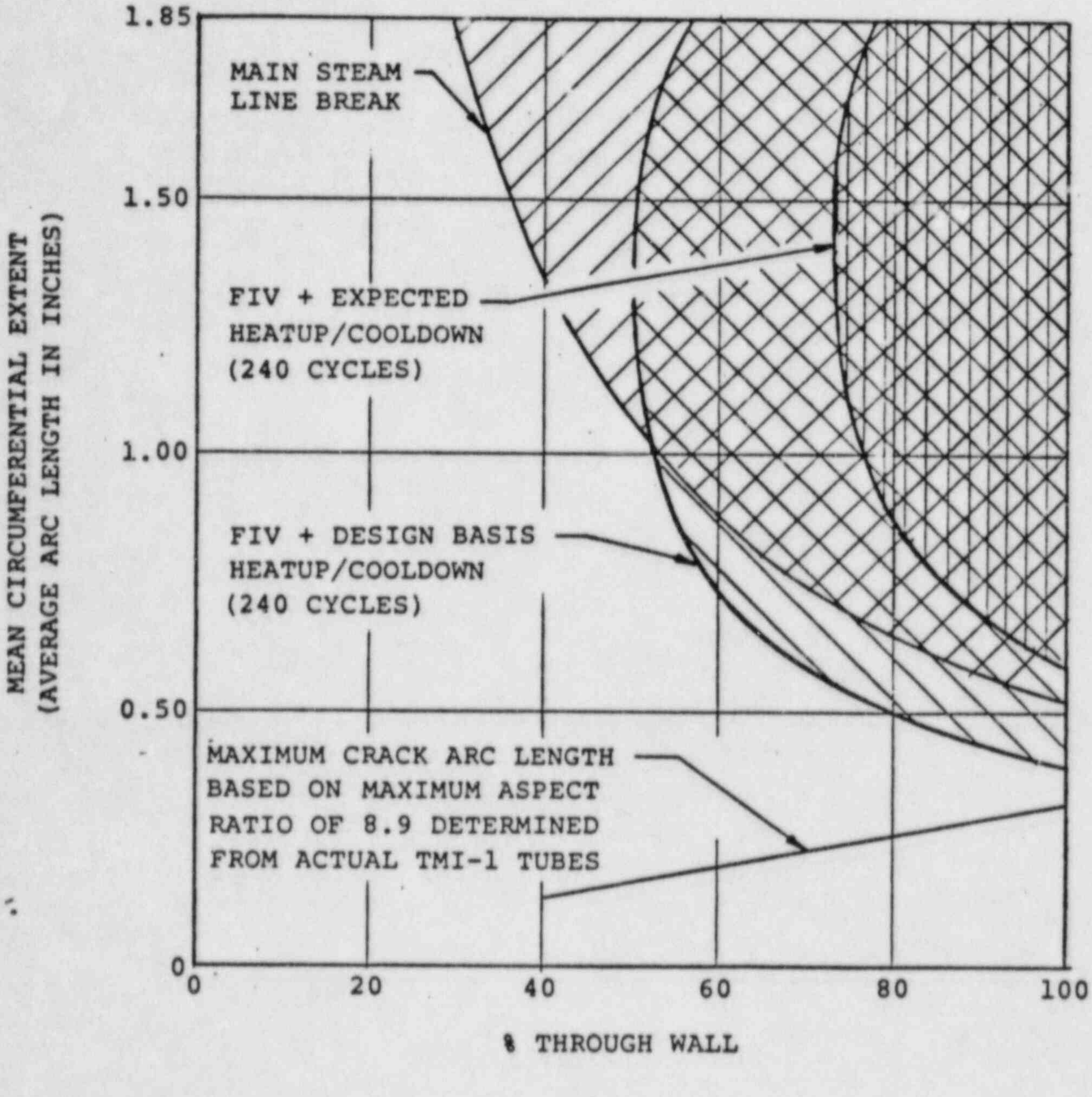


TYPICAL TMI-1 TUBE CRACK FROM 1981 INCIDENT



TUBE CAPABILITY COMPARED TO ECT DETECTABILITY

FIGURE III-2



TUBE CAPABILITY COMPARED
TO MAXIMUM OBSERVED EXTENT OF CRACKING
FOR PARTIAL THROUGH WALL CRACKS

FIGURE III-3

IV. STABILIZING CRITERIA

The stabilizing criteria used at TMI-1 is intentionally very conservative. Specifically, it not only ensures that all tubes which are calculated to possibly require stabilizers are stabilized; but it also ensures that a substantial number of other tubes are stabilized on the basis of conservatively applied engineering judgment (even though these tubes are not calculated to require stabilizers).

In essence, if a plugged tube is defective to an extent where it could become severed in any span between tubesheets, during normal operating conditions, then we conservatively assume that such a severed span of tube could vibrate over a long period of time and cause unacceptable wear on an adjacent tube. If such an adjacent tube were a non-plugged tube, such wear and wall thinning over a large area could in turn, during a transient, allow a large rupture and leak to occur from the reactor coolant system. Based on this, any defective tube that could become severed in any span between tubsheets due to normal operating loads will be stabilized.

Accident loads, e.g., main steam line break, are not of concern with regard to stabilizing because the time duration of an accident is relatively short and a non-stabilized tube, even if severed, would not cause any significant wear damage to an adjacent tube. Accordingly, only normal operating loads are of concern. Specifically, tube axial loads during cooldown (which place the tube in tension) are the loads of concern in determining the maximum allowable extent of a defect so as to ensure the tube will not sever unless it is protected by stabilizing.

The flow induced vibration stresses applicable to TMI-1 are insignificant in comparison to tube stresses during a cooldown transient as mentioned above. (See Sections VIII-G and H and Reference 9.) However, for added conservatism, tubes in a number of regions in the generator will be stabilized on an engineering judgment basis considering (i) the estimated extent of the defect (from special ECT not normally required or performed), (ii) the propensity for lateral vibration of the tube span in question, and (iii) the tendency of tube failures to occur as determined historically based on experience at other plants with OTSG's.

A. Summary of Stabilizing Criteria

The basic stabilizing criteria used at TMI-1 is presented in Section II. A more detailed summary of this criteria and the basic reasoning involved is outlined in Table IV-A.

B. Evaluation of Stabilizing Criteria

Each of the basic criteria requiring stabilizing in Table IV-A is evaluated as follows:

1. Any Detectable ECT Indication (Inside or Outside Diameter or any Depth) in 16th Span Including Bottom Four Inches of UTS and Within 15th Support Plate

This criteria covers the high cross flow tube span in the top of the steam generator as well as the first four inches of tube engagement within the upper tubesheet. This four-inch engagement is to ensure that even if a tube were postulated to become severed above this elevation that it could not get free and damage adjacent tubes. Notably, none of the tubes are expected to become severed at or near this four-inch elevation. For the case of kinetically expanded tubes, this four-inch elevation ensures there will be at least two inches of tube kinetic expansion available to carry the tube load. This two-inch expansion is nominally adequate to carry all required operating loads even if the tube were to sever at the four-inch elevation.

These tubes are not expected to become severed at the four-inch elevation because loads in this area would be small if present at all. Further, ECT data from the 8 x 1 absolute coil probe has been reviewed to ensure that there are no large (greater than 4 coils) cracks in these tubes at this four-inch elevation. Accordingly, the kinetically expanded portion of the tube above this four-inch elevation will provide substantially greater load capability for the tube than is needed; therefore, margins are large and this issue is not of concern. Finally, in the case of non-kinetically expanded tubes (plugged before kinetic expansion repairs) exposed to the 1981

cracking incident, the ECT data has been reviewed and there are no defect locations of concern regarding this matter.

This criteria is conservative since it requires stabilizing if any size or type of indication is detected by ECT in this span of the tube. To be further conservative, tubes in this category will be stabilized down to the 14th support plate as has been done before in other plants where substantial tube defects were found in the 16th span.

2. <u>Any Tube in Lane/Wedge Area (See Figure IV-1) that will be Plugged for any Reason</u>

This criteria is conservative since as a minimum it requires stabilizing if any ECT indication which requires plugging is found in the lane/wedge area, regardless of span. The lane/wedge area has been defined as that where there has been a greater than random failure rate in other plants with this type steam generator. Again, to be further conservative as in Item 1 above, tubes in this category will be stabilized down to the 14th support plate.

3. <u>Any Detectable (Inside or Outside Diameter) ECT Indication Greater than 40 Percent Through Wall in Any Tube Span Below 16th Span and within First 4 Inches of Bottom Tubesheet with 8 x 1 ECT Probe Signal on Three or More Coils</u>

Basically, this criteria provides a means for determining the tube arc length extent of a defect in order to decide if the tube should be stabilized. This criteria covers any tube span below the 16th span and includes the first four inches of the tube engagement within the bottom tubesheet. This four-inch engagement is to ensure that if a tube were postulated to become severed below this elevation, that it could not get free of the tubesheet and damage adjacent tubes.

This criteria is invoked and the tube would be stabilized at least within the tube span containing the ECT indication if there is any substantial size or arc length involved in the ECT indication. On the other hand, if an ECT indication is seen on less than three coils on the 8 x 1 ECT probe it means that the arc length of the degraded

area of the tube is a maximum of about 0.41 inch long at the inside diameter of the tube. Because of the "thumbnail" shape of the inside diameter cracks found at TMI-1 (see Figure III-1) this means that the average arc length of the largest two-coil ECT crack would be about 0.3 inch. This size crack is acceptable without stabilizing with margin as shown in Figure IV-2. See Reference 8 for further details on the correlation of 8 x 1 signals versus the arc length of the tube in degraded areas.

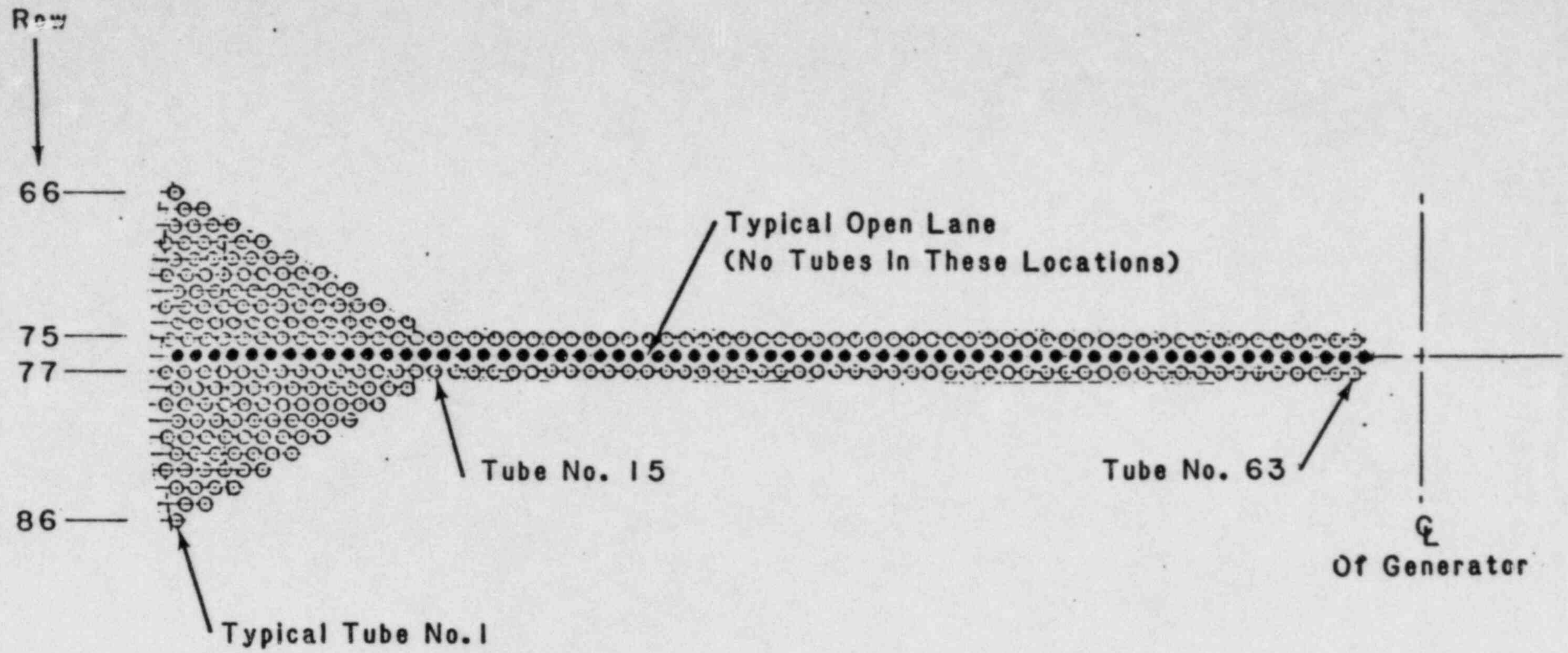
This criteria for stabilizing, based on arc length as measured by the 8 x 1 probe is not invoked for ECT indications less than 40 percent through wall because such an indication is too small to fail the tube. As can be seen from Figure IV-2, even if a tube were cracked 360° in arc length, the tube would not fail if less than 40 percent penetration even if 240 design basis load cycles were applied. Also and as mentioned earlier in this report, the maximum expected arc length of any crack of interest is only 0.65 inch (average through the tube wall). Even this size crack would result in considerable margin for the expected startups/shutdowns of TMI-1 even if the actual penetration were greater than 40 percent through wall.

<u>Alternative Criteria</u> -- Another type criteria for determining arc length extent of a tube defect has also been evaluated. This alternative criteria, although possibly not as accurate as the 8 x 1 criteria discussed above, is also considered adequate. However, it is not planned to be used except possibly in a few special cases, e.g., when 8 x 1 ECT data may not be available. The alternative criteria is based on correlation of ECT voltage versus volume of a defect and is presented in Section VIII-J.

Table IV-A

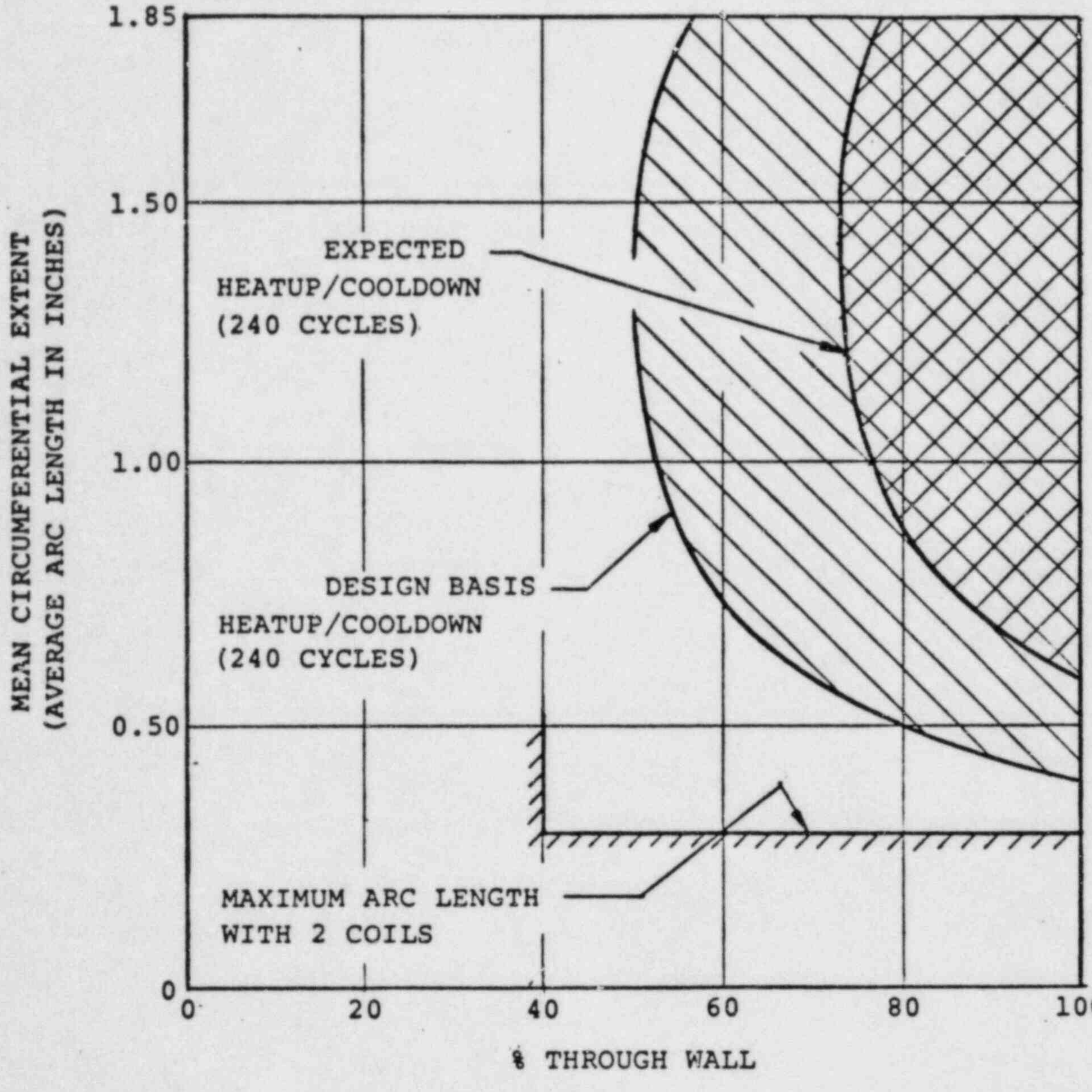
TMI-1 TUBES WHICH WILL BE STABILIZED (AND PLUGGED)

	ECT Indication	Comment
1.	Any detectable (inside or outside diameter or any depth) indication in 16th span including bottom 4 inches of UTS and within the 15th support plate	Provides maximum protection in high cross flow span
2.	Any tube in lane/wedge area (See Figure IV-1) that will be plugged for any reason	Protects local regions where tube failures have occurred in other OSTG's
3.	Any detectable (inside or outside diameter) indication greater than 40 percent through wall in any tube span below 16th span and within first 4 inches of bottom tubesheet with 8 x 1 ECT probe signal on three or more coils	Protects remaining regions inside the OSTG if tube is degraded to any substantial extent



LANE/WEDGE AREA OF TUBES TO BE STABILIZED
PER ITEM 2 OF TABLE IV-A

FIGURE IV-1



TUBE CAPABILITY COMPARED
TO 8 x 1 ECT PROBE SIGNAL ON TWO COILS
FOR DEFECTS GREATER THAN 40% THROUGH WALL

FIGURE IV-2

V. APPLICATION OF PLUGGING AND STABILIZING CRITERIA

For convenience, application of the plugging and stabilizing criteria presented in this report has been divided into two categories:

- Tubes plugged/stabilized after kinetic expansion repairs.
- Tubes plugged/stabilized before kinetic expansion repairs.

A. Tubes Plugged/Stabilized after Kinetic Expansion Repairs

The disposition of these tubes and the kinetic expansion repaired tubes is presented in Table V-A. Also presented in Table V-A is a summary of the technical bases which indicate the adequacy of each of the different tube/ECT categories involved. Finally, pertinent references are given where more detailed discussion is considered appropriate. As indicated, the tubes are considered to have been adequately dispositioned.

As mentioned in Section V.B below, the TMI-1 tubes were found to be cracked adjacent to and above the original tube-to-tubesheet (TTS) welds. This means that plugs which were welded after the 1981 tube cracking incident involved melting of these cracked tubes even though these plugs were welded to the original TTS welds. Accordingly, plug-weld over-cracked-tube tests were performed and these tests confirmed there were no problems, i.e., the tube cracks did not propagate up into the weld.

B. Tubes Plugged/Stabilized before Kinetic Expansion Repairs (See Reference 14)

The disposition of these tubes is presented in Table V-B. Also presented in Table V-B are the technical bases and pertinent references which demonstrate adequacy as in Table V-A.

Included in the technical bases column in Table V-B is a summary of justification of adequacy considering that portions of these plugs and their welds were exposed to sulfur contaminated reactor coolant system water during the 1981 incident. In essence, after metallurgical examination of tube/weld specimens removed from the upper tubesheet (UTS) at TMI-1 and after Dye Penetrant (DP) examination (see Reference 15) of tube welds and plug welds, the following was concluded:

1. The tubes and the weld heat affected zones in the tubes were cracked. Accordingly, and as shown in Item D of Table V-B, any plug welded only to the top of a tube will be either replaced or its weld will be repaired.

2. The original tube-to-tubesheet (TTS) weld and the cladding on top of the UTS were not cracked. Notably, this was not unexpected from a metallurgical standpoint because the cast structure (welds and weld deposited cladding) of the alloys involved is expected to be more resistant to corrosion cracking than wrought structures in the tubes. Accordingly, plugs which were welded to the original TTS weld did not need to be removed. Finally, for additional conservatism, a weld joint efficiency test simulating a worst-case cracked tube was performed and as expected, margins are very large and adequacy is ensured.

TABLE V-A

DISPOSITION OF TUBES PLUGGED AFTER KINETIC EXPANSION REPAIRS

ITEM	DETECTABLE ECT CATEGORY	NUMBER OF TUBES IN GENERATOR A	B	SUMMARY OF TECHNICAL BASES	DISPOSITION
A	Any indication above bottom six inches of kinetic expansion repair.			Satisfactorily repaired by kinetic expansion for all operating and accident conditions. See Reference 1	Kinetic expansion repaired in UTS.
B	Defect (≥40 percent TW) above US + 4-inch.			Load and seal capability of kinetic expansion below US + 4-inch are adequate for FIV and design basis normal loads even if maximum expected cracking at the US + 4-inch elevation. Further, cracking in this area has been confirmed as minor by 8 x 1 ECT. Therefore, tube will not become parted during normal operation. MSLB load is not a concern.	Roll plugs installed in UTS and LTS.
C	Any ID or OD indication in 16th span (from within 15th SP to US + 4-inch).			Provides maximum protection in high cross flow tube span.	Weld cap in UTS and stabilize to cover 16th and 15th spans. Explosive plug in LTS.
D	Defect (≥40 percent TW) in any span below 16th span including top 4-inch of LTS.				
	1. 8 x 1 probe, 2 coils or less.			Crack arc length adequately small with substantial margin if 2 coils. See Section IV.	Roll plugs installed in UTS and LTS.
	2. 8 x 1 probe, 3 coils or more.			Stabilize for additional margin.	Weld cap in UTS or LTS and stabilize within defect span from either UTS or LTS (depending, e.g., on ease of installation). Explosive or roll plug in remaining tubesheet.

TABLE V-A (Cont'd)

DISPOSITION OF TUBES PLUGGED AFTER KINETIC EXPANSION

ITEM	DETECTABLE ECT CATEGORY	NUMBER OF TUBES IN GENERATOR A	NUMBER OF TUBES IN GENERATOR B	SUMMARY OF TECHNICAL BASES	DISPOSITION
E	Any plugged tube in lane/wedge area. (See Figure IV-1)			Stabilize for additional margin, tubes in locations where failures have occurred in other plants with similar steam generators.	Weld cap in UTS and stabilize 16th and 15th spans. Explosive plug in LTS.
F	Any defect (≥ 40 percent TW) not covered in Items A through E.			Each tube evaluated on an individual case basis.	Roll plugs in UTS and LTS.
G	Detectable ECT indcation in any span below 16th span including top 4-inch of LTS (< 40 percent TW)				
	1. 8 x 1 probe, two coils or less.			Degraded area adequately small with substantial margin if 2 coils.	Leave as is and monitor ECT for future crack growth.
	2. 8 x 1 probe, 3 coils or more.			Plug for commercial reasons to reduce chance of leak but stabilizing not required because degraded area adequately small.	Roll plugs in UTS and LTS.

TABLE V-B

DISPOSITION OF TUBES PLUGGED BEFORE KINETIC EXPANSION REPAIRS

ITEM	CATEGORY	NUMBER OF TUBES IN GENERATOR A	NUMBER OF TUBES IN GENERATOR B	SUMMARY OF TECHNICAL BASES	DISPOSITION
A	Cap welded to original TTS weld in UTS and stabilized in 16th and 15th spans. Explosive plug in LTS. All installed after 1981 incident.			PT showed no cracks in original TTS weld and weld over cracked tube test showed no cracks in cap weld. Also, weld joint efficiency test showed very large margin. Finally, review of ECT below 16th span indicates no need to stabilize other spans.	Leave as is.
B	Taper plug welded to UTS cladding and explosive plug in LTS. All installed after 1981 incident.			Review of ECT data and stabilizing criteria in Table IV-A indicates no need to stabilize any spans and no cracks expected per Item A above. All tube goemetries evaluated including tubes severed (to remove tube sections for metallurgy tests) and FIV adequate without stabilizer per Section VIII-E and F.	Leave as is.
C	Roll plugs in UTS and LTS installed after 1981 incident.			Review of ECT data and stabilizing criteria in Table IV-A indicates no need to stabilize any spans except per Item 2 below.	
	1. Tube possibly severed at original roll transition in UTS.			Vibration characteristics adequate per Section VIII-E.	Leave as is.
	2. Tube in lane/wedge areas.			Stabilize for additional margin (based on history of tube failures in this area).	Remove UTS plug and stabilize in 16th and 15th spans and install weld cap in UTS.
	3. Balance of tubes with roll plugs in UTS.			No need for stabilizing indicated per tube evaluation on an individual case basis.	Leave as is.

TABLE V-B (Cont'd)

DISPOSITION OF TUBES PLUGGEL BEFORE KINETIC EXPANSION REPAIRS

ITEM	CATEGORY	NUMBER OF TUBES IN GENERATOR A	B	SUMMARY OF TECHNICAL BASES	DISPOSITION
	4. Balance of tubes with roll plugs in LTS.			No need for stabilizing indicated per tube evaluation on an individual case basis.	Leave as is.
D	Cap welded to original tube end in UTS and stabilized in 16th and 15th spans. Explosive plug in LTS. All installed before 1981 incident.			Reasonable to expect tube section to which cap is welded at UTS to be cracked during 1981 incident.	Either repair weld over tube section or remove and retain for possible future evaluations, the cap, and stabilizer. Install new weld cap (welded to original TTS weld on the cladding) and stabilize in 16th and 15th spans.
E	Explosive plugs in UTS and LTS, installed before 1981 incident.			Do not stabilize since consider that explosive plug in UTS is not cracked to extent that tube below was subjected to 1981 corrosive cracking. However, replug since tube above explosive plug may have been cracked.	Leave explosive plugs as is and install weld cap at top of UTS to ensure no leaks.
F	Cap welded during manufacturing in UTS to cladding in holes on open lane with no tubes below these holes.	63	0	PT indicates no detectable degradation of welds or caps and no tubes are installed below.	Leave as is.

Abbreviations Used in Tables

LTS	Lower Tubesheet
MSLB	Main Steam Line Break
SP	Support Plate
TW	Through Wall
UTS	Upper Tubesheet
US	Upper Tubesheet, Secondary Surface

VI. DESIGN ADEQUACY OF PLUGS AND STABILIZERS

A. Plugs

There are basically three different types of plugs used at TMI-1:

- Welded Plugs
- Explosive Welded Plugs
- Rolled Plugs

The material for all the plugs is Inconel 600. The qualifications of the welded and explosive welded plugs are covered in References 16 through 24. The qualifications of the rolled plugs are covered in References 12 and 13.

1. Welded plugs (Manual TIG) -- These plugs by B&W are essentially the same basic design as has been used at TMI-1 and at other OTSG plants and their adequacy has been justified previously. Included in the category of welded plugs are the welded caps used to support the stabilizers, the taper plugs used to seal holes in the UTS where tube samples were removed and other welded plugs used during initial manufacture to cover UTS holes in the open lane.

2. Explosive Plugs -- These plugs (by B&W) are the reduced charge type (to minimize tubesheet ligament distortion while still achieving a weld bond) and these plugs have also been used previously and their adequacy has been demonstrated.

3. Roll Plugs -- These plugs by Westinghouse are installed by use of a tube roller and they have been used previously although prmarily in recirculating-type steam generators. A substantial qualification program was undertaken to ensure these plugs are adequate for service at TMI-1. This program addressed pertinent technical questions including the effects of kinetic expansion in the tubes adjacent to a roll plug tube and the effect of tube cracks on the integrity of a roll plug joint.

B. Stabilizers

The stabilizers used in TMI-1 (by B&W) are the same basic design as has been used since about 1977 in a number of different plants. Only minor design changes such as rounding of sharp features has been performed and these changes are to increase fatigue resistance. The material for these stabilizers is Inconel 600, mill annealed. There is operating experience since about 1977 with a stabilized severed tube in a worst-case location -- namely with the tube severed at the UTS in the 16th span. Also, there is experience with non-severed tubes as well. Accordingly, these stabilizers are considered qualified and their adequacy proved by actual service experience. Finally, for additional assurance of adequacy and as presented in Sections VIII-E and F, the vibration adequacy of a stabilized severed tube has been calculated.

VII. REFERENCES

1. GPUN-TDR-007 Rev. 0, "Kinetic Expansion Technical Report."

2. GPUN SP-1101-22-014, "OTSG Post-Repair Eddy Current Examination."

3. Evaluation of Tube Samples from TMI-1, B&W Document No. RDD:83:5390-03:01 DTD July 7, 1983.

4. Final Report on Failure Analysis of Inconel 600 Tubes from OTSG A and B of Three Mile Island Unit-1 (Battelle), June 30, 1982.

5. Determination of Minimum Required Tube Wall Thickness for 177-FA Once-Through Steam Generators, BAW-1588, (B&W) April 1980.

6. Flow Induced Vibration Analysis of Three Mile Island Unit 2 Once-Through Steam Generator Tubes, Volume 1, EPRI NP-1876, June 1981.

7. Flow Induced Vibration of Oconee-2B OTSG Tubes, EPRI NP-1888, June 1981.

8. Three Mile Island Unit 1 OTSG Tubing Eddy Current Program Qualification (GPUN), October 1982.

9. GPUN Topical Report 008, "TMI-1 OTSG Return to Service SER."

10. GPUN TDR 400, "Guidelines for Plant Operation with Steam Generator Tube Leakage."

11. GPUN TDR 388, "Mechanical Integrity Analysis of TMI-1 OTSG Unplugged Tubes."

12. TMI-Unit 1 Explosive Tube Expansion Impact on Installed Rolled Plugs, November 1982 (Preliminary), by Westinghouse Electric Corporation, S. Sinha.

13. TMI-Unit No. 1 Steam Generator Tube Rolled Plug Qualification Test Report, April 1982 by Westinghouse Electric Corporation, E. Paxson.

14. Letter OTSG Tube Expansion Repair Program Disposition of Tubes Previously Removed from Service Letter No. GPUN 883-050, February 7, 1983.

15. QC Evaluation of Liquid Penetrant Testing in Unit 1 "A" & "B" OTSG Upper Tube Sheet, from J. Potter/N.D.E. Supervisor to S. Levine, TMI-1 6111-82-2207, November 18, 1982.

16. Welding Qualification for OTSG Nail Head Plugs to Tube/Seal Weld, TMI-1 Laboratory Report No. 86953, March 7, 1983.

17. Evaluation of OTSG Stabilizer Plug Weld (modified design for the expanded tubes),GPUN Laboratory Report 90668 and 90669, November 16, 1982.

18. B&W Document No. 32-1138428-00, "Weld Cap Stress Analysis" (for the new design cap), 32-1138428-00, November 15, 1982.

19. B&W letter GPUN-82-162, "Stabilizer Weld Cap-Minimum Weld Dimension," B&W-GPUN-82-162, TMI-82-056, June 18, 1982.

20. B&W Document No. 32-1127439-01, "MK-3 Explosive Plug Stress Analysis."

21. B&W Document No. 32-1134547-01, "Stress Report for Modified Nail Cap."

22. B&W Document No. 32-1132690-01, "Stress Report for Tapered Plug."

23. TMI-1 QC Plant Inspection Report PIR No. CS/33072/83, February 5, 1983, "PT Examination of the Welded Plugs Installed in Lane of the UTS."

24. Mettalographic Examination Results of Weld Caps Installed in June 1982, B&W Document RDD:83:5226-05:01 dated February 21, 1983.

EXIT MTG - THURS

3/24/83

- Ltr -

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O) ADEQUACY OF PROGRAM TO RETURN THE OTSG TO SERVICE

A) IP#6 - STAB + PLUG INSTALLATION PROCEDURE.

REF. TO INSPECTION REQUIREMENT OMMITTED.

SIMULTANEOUSLY DETERMINED BY LICENSEE.

REF TO INSP. REQUIREMENTS ADDED TO IP#6 VIA DRF (design review form)

B) -013 LACKING IN FIG. #3 SHOWING WPS# 04324 REV 0 TYPE NEW STABALIZER PLUG.

UNRL. - Will 013 T/TS Plug Standard for S.G. address new type plug.

→ Review completion require submittal / Review of other doc.

(Will Be Revised)

C) VISUAL INSPECTION OF PLUG WELDS

ENGINEERING JUSTIFICATION FOR CHOICE OF CODE REQ'D INSPECTION OPTIONS OF VT vs P.T. - 1/28/82 CONFER LTR.

Plug Weld - .027" - Enough? Engineering Response - Req'd

CONFER

UNRL

D) EC TESTING - DATA SHEET - CONAM.

REVISION OF DATA SHEET AFTER OPERATOR/ANALYST/REVIEWER SAMPLE OF FIVE TO DETERMINE JUSTIFICATION / CAUSE REASON FOR REEVALUATION AND FINAL EC DECISION

Will Review Response. (ISI

UNRL

E) ROLLED PLUGS - HAVE Ⓦ DETERMINE WHY ROLLED PLUGS LEAKED FOR CORRECTIVE ACTION IF POSSIBLE.

? 4% vs 12% vs Leak. Was 4% Production Actually Tested?

UNRL - (Dye check - prior to pull) -

Exit Mtg - Th[illegible]s

83-07

3/24/83

[illegible]

Page 1 of 4

F) QA verification overcheck of EC data in progress but not complete as of 3/21/83 Conam vs computer printout. (Tracking Item) - Waiting Results - UNRL.

ONE UNRL

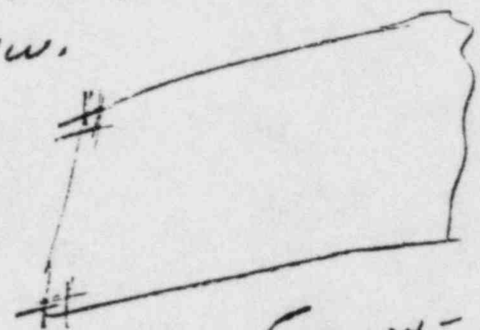
G) VT - Inspection Training Qual Records } Correlation of Training vs Welder Qualification Pass/Fail Results vs Visual Appearance.

→ 45.2.6 - Inspectors Adequate Training Qual of VT Inspector

No Specific Training =

H) Weldor Qual Samples & Records Requested for Review but not presented for NRC Review.

→ IFI



Summary

1) Welded Plugs - Engineering - Inspection { Concern -

2) Mechanical (Temporary Plugs) - Corrective Action for Leak Prevention. - Basis for 4% Being Adequate Roll.

3) EC Testing - Data Sheet Revision - Why/

4) VT - Training / Qual Records

5) Welder Qual - Training / Samples / Records

Reviewed

W 161E96 thimble plug (Thermally Treated Alloy 600)
161E56 Rev1 Modified Elliot Roller 1.612 Roller Pin Length
1612E58 Rev1 Hydraulic Plug Puller

C.V. Dodd to R.W. McClung (ORNL Interlab memo)
dated 8/17/82

W 2334D17 Rev1 Air Manifold
2334 D21 Tube mouth Rework Tool

B&W 100147 (D) TUBE REPAIR WELD CAP

B&W SKETCH TMI-1 OTSG PLUGGING CONFIGURATIONS (FIG.3)

W letter Jud Hughes to Wilkens (GPU) dtd 1/7/82
(Rolled Tube Plugging Services for TMI-1 - Technical
Description) - used at

GPU (TMI-1) SER BA 120002 R1 2/25/82

W WCAP 10084 TMI Unit 1 Steam Generator
Tube Rolled Plug Qualification Test Report
April 1982

GPU MTWS-012 Rev 0

GPU MTWS-013 Rev 0

3/24/83
SDR
Page 4 of 4

concerns & questions

a. adequacy of 0.027" restrained solid plug weld

b. copy of ASTM. A565 spec promised by Giacobbe of Tech Function

c explaination on where in WCAP 10084 it shows results of 4% wall reduction joints meeting design requirements for rolled plugs

d. explaination for 3rd review of EC tapes showing 95% of wall defects when first 2 reviews show NDD. If there is a spec change why is it no so indicated on disposition sheets

e evaluation of cause of failure of W rolled plugs

cc | S Young

GENERAL PUBLIC UTILITIES

OTSG REPAIRS

DATE 3/24/83

ITEM	DESCRIPTION	RESPONSIBILITY	DATE REQUIRED
1	Round Robin Samples		
1.	Restoration Secondary Side		
	A. Temp. Chem. System		
2.	Ops OTSG Status		
	. A and B OTSG Full Wet Layup		2/7
	. Ship Backing Plates for "A" Upper Manway		4/1
OTSG	A 62B 10" of N_2		
OTSG	B 575 10" of N_2		
3.	Post Expansion		
	. Felt Plug Blowing Device-Store at Reactor Bldg		
	. Final Freepath - Blow Plugs from Top		TBD
	. B&W Equipment		3/27
	. B&W Proposal		
	. Mt. Vernon Test → Friday		3/26
	Felt plug		
4.	Immunol Flush System		
	. Revised Spec for Flushing	T. Functions	TBD
5.	Tube Plug Stabilization		
	. M&C Procedure Requirements		
	IP4 Rev. 0 Remove W Roll Plugs	G. Kull	TBD
	IP5 Rev. 0 Tapered Plug Removal	G. Kull	TBD

problem when roll the plug
45±5 (is 45±5) 45 is max

Templates

GPU TECH SPEC REQUIRES VISUAL INSPECTION OF ALL TUBE THAT GET WESTINGHOUSE PLUG

A Taper plug
Remove three Westinghouse plug

OTSG REPAIRS — DATE 3/24/83

ITEM	DESCRIPTION	RESPONSIBILITY	DATE REQUIRED

6. Miscellaneous Items to Resolve
   . Hydrogen Peroxide Tube Soak

7. Waiting Documentation

MNCR		Responsibility
215-82	Plug Exploded at Wrong Area of Tube	B&W
345-82	2 Tubes Plugged Incorrectly	
354-82	Documentation for Immunol-1st Batch	Eng
426-82	Wire Brush B6-1	
009-83	Immunol at Cold Legs	
closed → 041-83	Tube Ends	Eng.
closed → 062-83	Omitted Stabilizer Segments	
067-83	40 mils vice 60 mils	
064-83	~~Explosive plug~~ holders slippage was low	
066-83	Explosive plugs	

8. Tube Endmilling

9. Rad Con Exposure Data (Based on SRDs) as of 3/23
   . Total OTSG Exposure since 1st Blast - 738.3 Man Rem
   . Total OTSG Exposure since Nov 1981 - 914.5 Man Rem

10. Bubble and Drip Test
    Final Detailed Spec — T. Reichter — 3/25

    Drip test review today will be done on Monday

11. Cleaning of the Cold Legs — S. Levin — 3/25
    Issue Purchase Requistion for Vendor

12. Anticipated Jumps

	Date	Description	Responsibility
231	3/24	A - Upper - Welding	Levin/Catalytic
		A - Lower -	
	3/24	B - Upper - weld inspection	
105		B - Lower - explose	

1) No blast last night
2) visual lift plus one plug
3) A otsg 3 stabilizat

GENERAL PUBLIC UTILITIES
OTSG REPAIRS

DATE 3/28/83

ITEM	DESCRIPTION	RESPONSIBILITY	DATE REQUIRED
1.	Restoration Secondary Side		
	A. Temp. Chem. System		
2.	Ops OTSG Status		
	. OTSG Level "A" - 576"		
	. OTSG Level "B" - 571"		
	. Ship Backing Plates for "A" Upper Manway		4/1
3.	Post Expansion		
	. Felt Plug Blowing Device-Store at Reactor Bldg		
	. Final Freepath - Blow Plugs from Top		TBD
	. B&W Equipment		3/27
	. B&W Proposal		
	. Results of Mt. Vernon Test → Equipment coming today		3/28
	Catcher too thin 150# AIR		
4.	Immunol Flush System		
	. Revised Spec for Flushing	T. Functions	TBD
5.	Tube Plug Stabilization		
	B → QC cat w done; lower mmy a plug w .536 26 tube too small		
	A Stab except 5 special plugs W- 3500 lbs will not move MVCR on two W plugs .1 mil under spec		
	A Explos 36		
6.	Miscellaneous Items to Resolve		
	. Hydrogen Peroxide Tube Soak		

OTSG REPAIRS DATE 3/28/83

ITEM	DESCRIPTION	RESPONSIBILITY	DATE REQUIRED

7. Waiting Documentation

MNCR		Responsibility
215-82	Plug Exploded at Wrong Area of Tube	B&W
345-82	2 Tubes Plugged Incorrectly	
354-82	Documentation for Immunol-1st Batch	Eng
426-82	Wire Brush B6-1	
009-83	Immunol at Cold Legs	
067-83	Endmilling to 40 mils 77-24	
064-83	Holders for Stabilizers	
069-83	ARC Strike on Adjacent Tube	
-	Rolled plugs	
	Misplaced explosive plug	

8. Tube Endmilling
   . Photos

9. Rad Con Exposure Data (Based on SRDs) as of 3/24
   . Total OTSG Exposure since 1st Blast - 743.9 Man Rem 752.5
   . Total OTSG Exposure since Nov 1981 - 920.1 Man Rem 928.7

10. Bubble and Drip Test
    Final Detailed Spec received 3/25 — T. Reichter — 3/25

    STP

11. Cleaning of the Cold Legs
    Nuclear Hydro 1.

12. Anticipated Jumps

Date	Description	Responsibility
3/28	A - Upper -	Levin/Catalytic
	A - Lower - Explos	
3/28	B - Upper -	
	B - Lower - Rolled / Explosive plugs	

Drip