OPERATION
WITH
LOOSE OTSG
TUBE SHEET PLUGS

CONTENTS

1.0 INTRODUCTION

Six (6) Westinghouse OTSG bottom tube sheet plugs are missing at TMI-1. Babcock & Wilcox has been requested to conservatively evaluate, using past experience and engineering judgement, the effects of loose plugs. For the purpose of the evaluation a population of loose plugs an order of magnitude greater than the number missing was selected.

The TMI-1 OTSG rolled plug is machined from Inconel 600 and thermally treated. Material of this type typically varies in degree of cold work from 0.0% to 10% (as annealed and thermally treated). The material is highly ductile within this range of cold work and, thus, the plugs are expected to be intact. The plug is hollow and weighs approximately 1.25 oz. The overall length is approximately 3.5 inches. The maximum outside diameter is approximately 0.6 inches and the smallest O.D. is approximately 0.5 inches. It requires a flow rate of only 8 ft/sec to lift the plug, therefore, the plug will be carried through the reactor coolant system until it reaches a location with insufficient flow area to allow the plug to pass. A plug weighing 1.25 ounces traveling at typical primary system velocities (20-60 ft/sec) would have an impact energy of less than 5 ft-lbs.

Any loose plug is expected to approximately maintain its original shape unless it finds its way to the top of the steam generator where the highly turbulent flow will tend to cause the plug to deform into a spherical shape as the result of repeated impact against the upper tube sheet.

The qualitative evaluation of these loose rolled plugs considers the Primary Pressure Boundary (Reactor Vessel/Primary Coolant System), reactor vessel internals, instrumentation, fuel assemblies, control elements, and other core components and potential access to lines attached to the reactor coolant system.

Table 1 is a tabulation of RCS Connections at TMI-1. Judgement of the likelihood of a plug or plug fragment entering these lines is based on the relative velocities of the primary RCS flow stream to that in the connection, the size of the connection and the orientation of the connection.

The evaluation addresses the following:

1. Identification of potential concerns including impact, wedging, wear, and flow blockage effects.

2. Qualitative estimation of the likelihood of actual occurrence and the probable consequences of each effect. For certain effects, an estimate of the worst-case consequences of the effect is provided.

2.0 SUMMARY AND CONCLUSIONS

Evaluation of core operation with loose OTSG tube sheet plugs has shown that safe operation of TMI-1 with such loose parts can be assured. The plugs will in all likelihood be held against the lower end fitting by the flow and be evenly distributed among the fuel assemblies. These considerations, along with the small plug population, allow the conclusion that potential for departure from nucleate boiling (DNB), fuel assembly lift and other adverse effects on operation with loose plugs will not create consequences that preclude safe reactor operation or shutdown.

The potential consequences of operation with loose plugs have been evaluated with respect to broken plug fragments and control rod interference. It was determined that access of fragments to the gap between the control rod guidance structure and the control pin is highly unlikely. Even if fragments enter this gap, decreases in rod drop time are less than those considered in existing Accident Analyses.

It was determined that plug fragments potentially escaping from the fuel assembly lower end fitting would not lead to further damage which would affect the safe operation of the plant. These fragments would be expected to be trapped in the first spacer grid without causing either fretting or DNB.

The postulation of a large number of plugs held by flow against one fuel assembly is judged highly unlikely. Even if it should occur it is not likely to cause DNB or operational problems. Even these highly unlikely events would not affect the health and safety of the public.

Although the population of missing plugs is 6, the results of the evaluation lead to the conclusion that TMI-1 could operate with an order of magnitude greater than the number of missing OTSG bottom tube sheet plugs without endangering the health and safety of the public.

3.0 EXPECTED CONSEQUENCES OF OPERATION WITH LOOSE PLUGS

3.1 Loose Plugs in the Primary Coolant System

The loose plugs that fail to remain in place in the steam generator are expected to pass out of the steam generator, through the cold leg piping and reactor coolant pump, into the reactor vessel and ultimately be held against the lower end fittings of the fuel assembly by the flow.

A whole plug is 3.5 inches long and 0.6 inches in diameter. A plug weighing 1.25 ounces traveling at typical primary system velocities would have an impact energy of less than 5 ft-lbs. A plug of this size is of no consequence to the reactor coolant pumps and will be carried through with the reactor coolant fluid. The impact of the plugs on the fuel assembly or reactor pressure boundary will have no adverse effect due to the low impact energy.

Past operating experience indicates that a 1.25 oz. plug will have insufficient impact energy to damage the fixed incore instrumentation or its guidance structure. Surveillance requirements and Technical Specification limits are in place regarding the incore instruments and their signals. Should a string be damaged, its output would be noted and corrective action would be taken.

Furthermore, there is no indication from Operating Plant Experience that plug fragments, should they exist, would find their way into the incore instrument guide tube and prevent the removal of the instrumentation during refueling.

Engineering judgment based on the relative size of the OTSG plug, gaps between mating parts and pressure boundary closure surfaces leads to the conclusion that there is no location in the reactor coolant system where a plug could become lodged and generate sufficient local stress during a heat-up or a cool-down to damage the pressure boundary. Thus, loose plugs or plug fragments would not cause damage to the RCS which could affect the safe operation of the plant.

The only instrumentation in the cold leg of the primary coolant system are the cold leg RTE's (Resistance Temperature Elements). The instrumentation in the hot leg of the Primary Coolant System are the Flow Meter Impulse Nozzles, and the hot leg RTE's.

The RTE's protrude into the fluid flow, but only by one inch. It is considered highly improbable that 1.25 ounce object would be able to cause any damage to the RTE. However, in the unlikely case that the pressure boundary housing is damaged, the detector inside provides a second pressure boundary which would prevent primary coolant leakage. In addition, in the unlikely case that the function of the RTE was impaired, it would most likely fail high. That is, it would indicate a higher or infinite resistance, and therefore temperature. This would not compromise any safety systems since the RTE's initiate a reactor trip on high temperature based on two RTE indications.

The Flow Meter has eight impulse nozzles which project into the fluid flow; however, these impulse nozzles are fabricated as substantial blocks of material which can easily withstand the impact of a 1.25 ounce object traveling at the full velocity of the hot leg fluid.

3.2 Fuel Assembly Flow Blockage

The plugs are most likely to be held against the lower end fittings by the reactor coolant flow. Since the plugs would likely be evenly distributed among the fuel assembly lower end fittings, the flow blockage upstream of the fuel active length would be minor. The effect of the flow blockage caused by one or two plugs in a fuel assembly is insignificant. The redistribution of flow downstream negates any potential effect of such a minor flow blockage.

Post Irradiation Examinations of B&W fuel assemblies that have operated in reactor coolant systems with debris have shown that small fragments which pass through the end fitting become trapped in the first spacer grid and do not result in fuel rod failure from either fretting or DNB. In the highly unlikely event that a single fuel rod or small number of fuel rods were damaged, the leakage of the fission products would be expected to be well within the Technical Specification Limits and would be noted by activity increases.

4.0 EFFECTS OF LOW LIKELIHOOD OCCURRENCES

4.1 Loose Plugs at the Top of the Core

Loose plugs could possibly be carried to the top of the core by traveling through the core bypass between the core baffle plates and the core support cylinder. However, this scenario is judged highly unlikely because of the torturous flow path and small openings through which plugs would have to pass.

It is not possible for whole plugs to enter the guidance structure at the interface between the upper end fitting and the guidance structure due to the small openings. Any plugs above the core could not gain entry into the control rod guide structure because of the continuous flow out of the structure for all flow configurations. In control rod locations the flow exits the fuel assembly by multiple paths in the upper guide tube structure as shown in Figure 1. Approximately 60% of the total flow exits the column at the lower set of flow holes. The remaining flow (approximately 40%) exits the top of the column and is sufficient to prevent a plug from entering the column.

Operating Plant Experience indicates that all loose parts that find their way to the top of the core will be swept to the top of the steam generator. No components in the plenum assembly can be damaged by the plug.

4.2 Loose Plugs at the Top of the Steam Generator

A whole plug or large plug fragment could end up on the steam generator upper tube sheet and be undetected because of its size. Generally, the noise monitoring system can detect objects four ounces and larger.

It is unlikely that in the case of continued reactor operation, a 1.25 ounce plug or smaller plug fragment would cause any damage to the tube-to-tubesheet weld.

If, however, some damage were caused to this connection, it should be minor and should not affect the pressure boundary integrity of the tube-to-tubesheet weld due to the extremely low impact energies. Since the Steam Generator tubes were expanded within the tube sheet using the Kinetic Expansion process, the likelihood of leakage at this boundary is even less probable. In the case that some primary to secondary leakage did occur, it would be monitored from the secondary side.

4.3 Loose Plugs in Connections to the Primary Coolant System

Although a low likelihood is assigned to the possibility of a plug or a fragment entering a line off the RCS, the potential consequences for this low likelihood event are given below. The single penetration for which the likelihood is judged other than extremely low is for the Decay Heat Drop Line shown as Item 4 of Table 1.

4.3.1 Decay Heat Drop Line

During power operation the Decay Heat Removal (DHR) system is isolated from the RCS. However, when in use, there is a relatively unobstructed flow path from the decay heat drop line nozzle to the DHR pump suction which could permit the passage of one or more tube plugs to the operating pump. OTSG tube plugs being moved through the system by forced RCS flow must be transported to the region of the DHR drop line (near the RV outlet) and then collect in the short dead leg between the DHR system drop line connection and the isolation valve, an unlikely set of circumstances given the obstacles blocking passage through the reactor vessel.

However, if this were to occur, it could result in degradation of DHR pump performance when the system was placed in service. It is extremely unlikely that tube plugs reaching the DHR pump suction could cause a catastrophic failure. The most probable result would be damage to the impeller causing an out of balance condition that might shorten bearing or wear ring life. Pump delivery rates would not be affected.

The system design does provide redundancy to deal with potential failures. Plant Technical Specifications ensure this redundancy by restricting plant operation when both DHR trains are not available. In addition TMI-1 has been operated in various plant modes since the tube plugs were installed in April of 1983, including significant periods of time with and without reactor coolant pumps running and with the DHR system in service. To date, no DHR functional degradation or other anomalies have been noted.

If a problem does develop before plant heatup begins, plant operators will have ample time to diagnose the problem, start up the redundant DHR train, and take remedial actions to repair the system. Hence, problems developing within the DHR system are within the design of the system and the capabilities of operating staff to mitigate with no loss of DHR function.

5.0 EFFECTS OF EXTREMELY LOW LIKELIHOOD OCCURRENCES

5.1 Massive Flow Blockage

Massive flow blockage resulting from many of the loose plugs or plug fragments collecting in the same fuel assembly could possibly cause fuel assembly lift and/or departure from nucleate boiling (DNB). However, the likelihood of massive flow blockage in even one fuel assembly is extremely remote. Even for the worst case considered, an order of magnitude greater number of loose plugs than those missing, the distribution of plugs would be more or less random with less than one plug per fuel assembly expected. For the existing case, 6 missing plugs, the likelihood of multiple plugs per assembly is even more remote. Nevertheless, the discussion that follows addresses the effects of a postulated massive flow blockage.

5.1.1 Fuel Assembly Lift

In the extremely unlikely event that a sufficiently large number of plugs or plug fragments collect in a fuel assembly to cause massive flow blockages, then that fuel assembly might lift off the grid pads. Although fuel assembly lift is not anticipated under any circumstances, fuel assembly lift was evaluated. Since the normal lift margin is approximately 200 lbs. at TMI-1, it is difficult to theorize any real potential for fuel assembly lift. Nevertheless, a fuel assembly experiencing lift could move upward a maximum of 1.5 inches, with a corresponding impact energy level of less than an order of magnitude lower than the energy necessary to damage the fuel assemblies, 500 ft-lbs.

There have been several tests run to determine the flow required to cause fuel assembly lift. These tests which were performed at reactor conditions (flow, pressure, and temperature) also provide an indication of assembly vibration levels in the lifted condition. There has been no indication of vertical oscillation of the assembly during these tests.

Also, the fuel assemblies were examined after each test and no evidence of impact or wear was found. These results indicate that severe vibration will not result for a lifted assembly.

5.1.2 Departure from Nucleate Boiling

If a massive fuel assembly flow blockage is postulated, DNB could result. However, tests of pressure and flow in model Babcock & Wilcox fuel bundles containing blockages have shown that flow in a blocked subchannel would recover to about 90% of nominal value about 13 inches downstream of the blockage and fully recover before reaching typical elevations at which minimum DNB occurs.

If the massive flow blockage was assumed to cause DNB, then no propagation of DNB would occur because the surrounding channels will have higher than average flow as a result of the blockage and only a small number of pins would fail. Thus, any massive fuel assembly flow blockage by loose OTSG plugs will not affect the health and safety of the public.

5.2 Plug Fragments in the Upper Guide Tube Structure

No scenario has been developed that could lead to whole plugs interfering with the control rods. However, there are locations within the guide tube column where plug fragments could conceivably be deposited such that the control rod motion would be resisted. While this possibility does exist, it must be noted that such an event is highly unlikely because the plugs are not expected to fragment. If a fragment did exist, it would have to work its way up the entire length of the fuel assembly and enter the gap between the control pin and the control rod guidance structure while the flow exiting the end fitting is sufficient during normal operation, to sweep the plug fragment out the top of the guide tube column.

5.2.1 Effect on Safety Analysis

If it is assumed that plug fragments manage to enter the control rod structure, then there exists the potential of increasing the mechanical drag on control rods during SCRAM insertion. Any increased drag retards the motion of the control rod during insertion. Thus, the possibility exists for a limited number of control rod assemblies to experience slower CRA drop times than would normally be expected for reactor trip.

The Safety Analyses of postulated events relies on negative reactivity insertion from the control rods for accident termination. The CRA drop time used in the Safety Analysis is conservatively slower than that experienced in field performance tests. Field tests on drop times required prior to each cycle restart show results in the range of 1.1 to 1.3 seconds to 3/4 insertion, versus a conservative value of 1.66 seconds to 3/4 insertion which is typical of Safety Analysis calculations for 177 Mark B fuel assembly cores.

The accident analyses performed for the Safety Analyses Report for any 177 FA core includes a study of the sensitivity of results to a delay in control rod insertion. This is normally performed for the overheating transients of Rod Group Withdrawal at HZP and Rated Power Condition. These accidents can result in overpower and overpressure conditions in the primary system. Accident analyses have been performed for sensitivity to trip delay time by delaying the initiation of rod motion by up to 1.0 second. Peak RC system pressures are increased on the order of 20-39 psi for these increased trip delay times.

It has been determined that an assumed 50 pound axial drag force has the effect of increasing the drop time to 3/4 insertion by only 0.35 seconds. Based on engineering judgment, the plug fragments should contribute less than the assumed 50 pound drag force. This increased drop time is within the delay time considered in the sensitivity study performed for overheating events. Thus, these potential consequences of loose OTSG plugs will not have an effect on the Safety Analysis.

5.2.2 Shutdown Capability

The potential for completely preventing control rod insertion is quite remote. However, in the unlikely event control rod motion is prohibited, sufficient control rod reactivity capability exists to provide reactor shutdown.

When shutdown analyses are performed, it is conservatively assumed that one control rod assembly (CRA) having the maximum worth compared to all other rods, is stuck such that it will not drop into the core. These shutdown analyses also include additional conservative assumptions such as rod worth uncertainties and time in core life. Also, a shutdown margin of 1%Δ k/k or more is maintained by Technical Specification by placing restrictions on control rod insertion. Thus, if the maximum worth stuck rod is caused by control rod interference due to loose OTSG plugs, a 1%Δ k/k shutdown margin is assured by normal shutdown analyses and Technical Specification limits.

To reduce the likelihood of a stuck control rod caused by loose OTSG plugs or any other means, Technical Specifications require frequent control rod exercising. If an inoperable rod is identified, corrective action is taken as required by Technical Specifications.

5.3 Effect on Large Break LOCA

The limiting Large Break LOCA is a break in the cold leg piping. This event is characterized by an almost instantaneous flow reversal, core dry-out, and core reflood. The flow reversal would probably carry all loose plugs located below the lower end fittings away from the core without impacting the system response. Any loose plugs in the core vicinity would not affect the reflooding rates and, therefore, would not affect the results.

5.4 Loose Plugs in Connections to the Primary Coolant System

Although an extremely low likelihood is assigned to the possibility of a plug or fragment entering connections other than the Decay Heat Drop Line the potential consequences are addressed below for two other penetrations; the High Point Vent Lines and the Letdown Line to the Makeup System.

5.4.1 High Point Vent Lines

The high point vents, Item 3 of Table 1, are used for normal fill and vent of the RCS during cold conditions; during hot pressurized conditions, they are intended to simplify plant recovery operations following ICC (Inadequate Core Cooling). During ICC large volumes of non-condensible gases may be generated and collected in the RV head, pressurizer, and/or hot legs, thus complicating RC pressure and inventory control. The vents provide a direct discharge path for these gases from the RCS, thus eliminating the need to depressurize the RCS through the PORV or be held up by the inability to remove a bubble.

TMI-1 has four such high point vents: one in each hot leg, one in the pressurizer, and one in the RV head. These provide independent means of discharging non-condensibles or steam from the RCS. Because of the low velocities in the RV head region, blockage of the head vent by a tube plug is highly unlikely.

Blockage of the pressurizer vent line is virtually impossible since upward velocities are extremely low in the pressurizer. Blockage of one or even two of these vent paths would not eliminate the venting function. In addition, each vent line has two valve isolation. Were a tube plug to lodge in an open valve, a second valve could isolate the penetration.

In any event, the vent flow is less than the makeup system capacity.

5.4.2 Letdown Line to the Makeup System

The letdown portion of the makeup system, Item 8 of Table 1, is not assumed functional for safety analyses. The design basis for TMI-1 does not require the use of the letdown line or makeup system to reach cold safe shutdown. During plant cooldowns, the letdown portion of the makeup system and other auxiliary equipment are used to borate the RCS. If emergency boration of the RCS is ever required, alternate means exist including use of the HPI system and one of the four RCS high point vents.

In addition, the likely collection point for debris in the letdown system is the letdown coolers. There are two of these coolers in redundant trains providing suitable backup capability. The small size of the plugs themselves or any part thereof make it highly unlikely that complete flow blockage could occur anywhere in the letdown system. Partial blockage could cause a minor operational problem.

5.4.3 Remaining Connecting Lines

Items 2, 7, 10, 11 and 13 of Table 1 are all drain and pressure test connections. Normal plant operations proceed with all these lines valved off. It is extremely unlikely that a plug would enter any of these connections. In the event that a plug or fragment entered these lines the expected consequence would be a reduced drain or flow rate and would not be a safety concern. It would be noted during operations and would be expected to be readily remedied.

A plug entering the pressurizer surge line, Item 1 on Table 1, could be transported into the pressurizer by a pressurizer insurge. The plug would then remain in the bottom head of the pressurizer causing no operational or safety concerns.

A plug entering a pressure sensing connection on the hot leg, Item 5 in Table 1, would not be a problem because there is no flow to move the plug down the line. Flushing the sensing line could move the plug toward the transmitter. However the plug could not effectively block the line and pressure readouts would be unaffected unless debris collected in the bellows chamber itself. In any case, each hot leg has redundant pressure instruments off different sensing lines. This provides a readily available means for detecting differences in instrument performance. The problem is not assessed to be a safety concern.

It is virtually impossible for a plug to enter the flow impulse nozzle on the flow meter, Item 6 of Table 1. These nozzles lead to manifolds (upstreams to one manifold, downstreams to a second manifold). Even if a nozzle were blocked, the pressure signal would be unaffected.

For Items 9 and 14 of Table 1, the HPI lines and the CF injection lines, a plug could not be transported down the line because these lines provide flow into the RCS. When the line is placed in service, the plug would be transported back into the RCS.

For the spray line to the pressurizer, Item 12 in Table 1, a plug could be stopped by one of the spray line valves or by the spray nozzle which could reduce the attainable pressurizer spray flow rate. The spray line contains redundant valves to isolate all but the trickle bypass spray flow, providing a means for the operator to stop a continuous spray down if valve operation becomes impaired. Since RCS pressure control by pressurizer spray is not assumed for safety analyses, no FSAR assumptions would be invalidated by a loss of a reduced spray capability. Partial or complete loss of spray function, or the impaired operation of one of the spray valves does not constitute a safety concern.

6.0 SYNOPSIS

The expected consequences of operation with loose OTSG plugs has been examined with respect to fuel assembly flow blockage and loose plugs in the cold leg of the reactor coolant system. The effects of low probability occurrences such as loose plugs at the top of the core, in the hot leg of the reactor coolant system, and in the steam generator were also examined.

Furthermore, the effects of extremely low probability occurrences such as massive flow blockage that might result in fuel assembly lift or departure from nucleate boiling and plug fragments in the upper guide tube structure were evaluated.

Although the population of missing plugs is six, the results of the evaluation lead to the conclusion that TMI-1 could operate with an order of magnitude greater than the number of missing plugs without endangering the health and safety of the public.

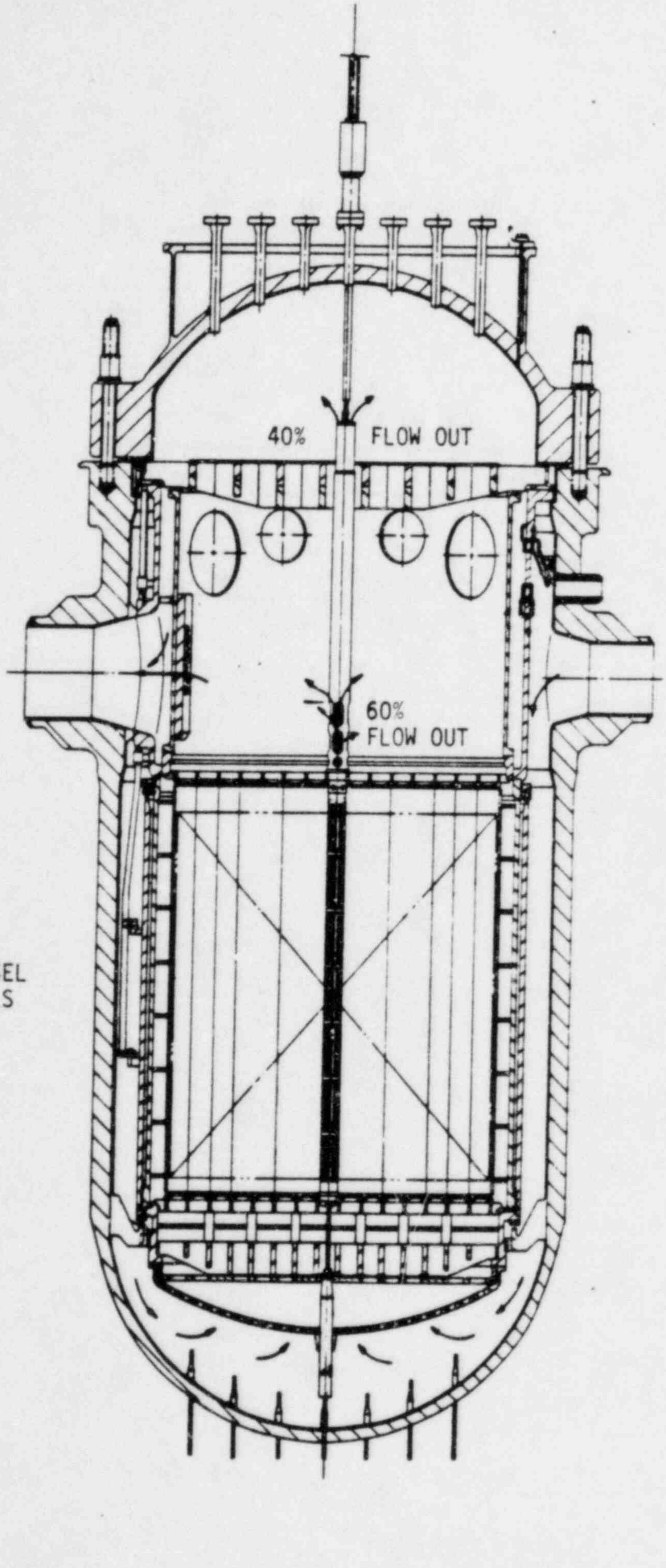
TABLE 1
CONNECTIONS TO THE RCS PRIMARY SYSTEM AT TMI-1

Hot Leg (HL) Connections

	Connection ID (")	Connection Orientation	Remarks	Likelihood of a plug/ Fragment Entering
1. Pressurizer Surge Line (1)	8.75	Side of Vertical HL	Surge diffuser has 4 ports (each 3.2" x 4.1") dis-charing radially	Extremely Low Likelihood
2. Surge Line Drain (1)	0.815	Bottom of Horizontal surge line		Extremely Low Likelihood
3. Vent line (4)	0.815	Top of U-bend(s) Pressurizer Head Reactor Vessel Head	All connecting lines have globe valves.	Extremely Low Likelihood
4. DH Drop Line (1)	10.5	Bottom of Horizontal HL		Low Likelihood
5. Pressure Taps (4)	0.815	Side of Vertical HL		Extremely Low Likelihood
6. FLow Meter Impulse Nozzles (16)	Appears to be 0.651D	8 face upstream 8 face downstream		Extremely Low Likelihood

Cold Leg (CL) Connections

	Connection ID (")	Connection Orientation	Remarks	Likelihood of a plug/ Fragment Entering
7. Drain Line (3)	1.338	Bottom of J-leg	Drain valve is globe Valve	Extremely Low Likelihood
8. Letdown Line to MU System (1)	2.125	Bottom of J-leg		Extremely Low Likelihood
9. HPI Lines (4)	1.5" ID Thermal Sleeve	Side of 45° Inclined CL		Extremely Low Likelihood
10. Pressure Test Connections (2)	0.815	Side of Vertical CL	Isolation valve is globe Valve	Extremely Low Likelihood
11. Pressure Test Connections (2)	0.815	Side of Horizontal CL	Isolation valve is globe Valve	Extremely Low Likelihood
12. Pressurizer Spray Line (1)	2.125	Side of Horizontal CL	Spray Valve is Rockwell Globe Valve	Extremely Low Likelihood
13. OTSG Bottom Head Drain	0.815	Center of Bottom Head	Drain Valve is Globe Valve	Extremely Low Likelihood
14. CF Nozzle on Reactor Vessel (2)	9" dia. Insert	Side of Reactor Vessel		Extremely Low Likelihood



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