

**Draft NRC Test Plan
Integrated Chemical Effects Leading to Additional Sump Blockage**

(Preliminary Draft for Discussion Only)

Background

On March 28, 1979, a stuck-open pressurizer relief valve, and eventual use of the emergency core cooling system, led to the escape of a substantial amount of reactor coolant, including some radionuclides. The NRC Fact Sheet on the Three-Mile Island (TMI) accident tells the rest of this background: “Shortly after the accident began, some of the water, carrying fuel debris and fission products, escaped from the reactor coolant system and flowed into the reactor building basement. By the time the accident had ended, the water in the basement had been heated by residual heat from the reactor vessel, evaporated, condensed on the walls, and drained down onto the floors and back into the basement. The radionuclides then permeated into the porous surfaces of concrete and layers of iron which later became corroded (this area of the plant became a major focus of the subsequent clean-up and decontamination)” [1]. Reports from the time indicate that the total volume of the sump water was about 570,000 gallons; about two-thirds of that was from the reactor water storage tank, and about one-third was from the Susquehanna River. The maximum pool depth was about eight feet. 153 days after the loss-of-coolant accident (LOCA), TMI containment water with gelatinous precipitates covering the containment floor was recovered and analyzed [2]. The results of that analysis are recorded in Appendix B.

On July 28, 1992, a steam line loss-of-coolant accident (LOCA) occurred when a safety relief valve inadvertently opened in the Barsebäck-2 nuclear power plant in Sweden. The steam jet stripped fibrous insulation from adjacent pipework. Part of that insulation debris was transported to the wetwell pool and clogged the intake strainers for the drywell spray system after about one hour. Although the incident in itself was not very serious, it revealed a weakness in the defense-in-depth concept which under other circumstances could have led to the emergency core cooling system (ECCS) failing to provide water to the core [3].

The purpose of the GSI-191 study [4] is to determine if the transport and accumulation of debris in a containment following a LOCA will impede the operation of the ECCS by increasing the head loss across the sump pump strainers. The purpose of this test plan is to determine whether or not some type(s) of gelatinous material similar to that found on the TMI containment floor may exacerbate the sump strainer head loss either by (a) chemically reacting with or (b) agglomerating onto the insulation and other debris that may block the sump strainer. It is important to note that the objective, or attempted result of this study, is not to replicate the gel material found at TMI, for that incident is considered atypical for a number of reasons, including the presence of damaged fuel and river water. The objective is to determine if there are plausible reactions that may occur post-LOCA (but without severe accident), that would produce chemical compounds that would degrade the ability of the sump strainer to pass water sufficient enough to

maintain the required recirculation rates. This difficulty in working toward a relatively unspecified objective is discussed further in “Procedures” section.

Typical time-temperature-pressure profiles regarding the thermal-hydraulics of various sized LOCAs in ice condenser and large dry containments is detailed in Appendix A from data in references 4 and 5. The calculations in these references are based on use of the RELAP5 or MELCOR codes, and are thus considered to be representative, given that reasonable pre-LOCA conditions were assumed, as were other relevant parameters such as containment volume.

A recent Los Alamos National Laboratory (LANL) report [6] coupled with the ORNL data [2] forms the basis for the chemical aspects of this test plan. This test program aimed at establishing the conditions for production of the gelatinous material under laboratory conditions that simulated the time-temperature characteristics of representative LOCAs. The LANL analysis conducted at the University of New Mexico (UNM) did not have access to the ORNL data and as such investigated a different compositional range of major constituent elements, i.e. no Cu, Ni, Mg, S, Cr, etc. The details of the chemistry are provided in Table 1. At the time, both industry and the LANL/UNM considered the following major constituent additives in typical cooling-system waters appropriate for this test program:

- Al from scaffolding and insulation jackets
- Fe from corroding steels
- Zn from paint leaching and corroding galvanic coatings
- Ca from eroding concrete

It should be noted that the industry’s plan (Test Plan dated November 12, 2003) also accounted for both Mg and Si which they said will be present due to the concrete dissolution. Table 2 shows the differences between the following parameters from the ORNL TMI containment water measured values to the industry’s and LANL/UNM simulated cooling-system test waters:

- the amount of B and Li additions
- the use of different basic pH moderators, NaOH vs Na₃PO₄
- different pH test ranges.

Obviously, the amount of dissolved cationic additions in both the LANL/UNM report and industry’s test plan must be reconciled with the ORNL TMI data which shows relatively high amounts of Cu, Ni, and S unlike the others. Further work is also needed to assess where these elements originated from and whether they play a significant role in the precipitation of the gelatinous material. The lack of quantitative amounts of corrosion products from the industry’s test plan also confuses the situation. Typical corrosion rates from AA6061-T6, AA5052, galvanized coatings, etc. could be used to determine appropriate upper and lower bounds of plausible corrosion product concentrations in the industry’s planned simulated cooling-water solution. These could then be correlated to the ORNL data for comparison to the TMI chemical analyses.

Table 1. Test Matrix of Dissolved Metal Additions to Simulated Cooling Water [6]

Test ID	Test Matrix for Metals Added during the Chemical Precipitation Concentration (ppm)			
	Al	Fe	Zn	Ca
5a	269.8	558.5	653.8	400.8
5b	54.0	111.7	130.8	80.2
6a	269.8			
6b	54.0			
6c	27.0			
6d	134.9			
6e	6.7			
6f	2.7			
7a		558.5		
7b		111.7		
7c		55.8		
7d		27.9		
7e		5.6		
8a			653.8	
8b			130.8	
8c			13.1	
8d			3.3	
9				4.0
10a	5.4			
10b	13.5			
10c	21.6			
10d			13.1	
10e			26.2	
10f			52.3	

Table 2. Differences in Simulated Cooling-System Waters

Species	Concentration (ppm)		
	ORNL Data (Bottom)	LANL/UNM Data	Industry Plan
B	1,900	357 ^a	2,500
Li	1.44	1.4	0.1
HCl	No pH Moderation	Acidic Additions for pH Control (pH = 7.0-9.0)	Acidic Additions for pH Control (pH = 6.5-9.5)
Na ₃ PO ₄	No pH Moderation	-	Basic Additions for pH Control (pH = 6.5-9.5)
NaOH	No pH Moderation	Basic Additions for pH Control (pH = 7.0-9.0)	-

^a Calculation error by LANL/UNM since they wanted 2,000 ppm boron as boric acid

Objective

The objective of the test plan is to develop and operate a circulating water test loop with temperature and chemistry control to determine whether similar gelatinous reaction products may develop in the typical time-temperature-chemistry regime following a LOCA event. Tests will be conducted using justifiable proportions of non-metallic (paints, thermal insulation, electrical insulation), metallic (mainly Al from reflective insulation and Zn from galvanized structures), and cementitious materials, from dust particulates and soluble concrete exposed to the warm, slightly basic pH of the containment pool.

Procedure

The test plan is divided into two phases, and the first phase is divided into two distinct efforts.

Phase 1A: Calculation of Plausible Reaction Products

Given the range of temperatures, water quality (pH, hydrogen content, etc.) and contaminants available, we need to narrow down the list of critical variables, constituent concentrations, and time-temperature parameters that will be selected for the actual laboratory tests. As the inputs for typical time-temperature-chemistry profiles are now available, the use of a qualified and established computational thermodynamics program (e.g. Environmental Simulation Program (ESP) by OLI Systems, Inc, Geochemists' Workbench, or an equivalent program) can be applied to multicomponent and multiphase (i.e. liquid, gas, and solid) systems to identify the likely chemical species formed during well defined thermal-hydraulic processes. In other words, these types of programs can be used to determine the evolving chemical speciation, concentration variations, and precipitation amounts and chemistries, as a function of pool temperatures, pH, pressure, and parametric inputs of the likely constituents. The chemical speciation results from computation can then be used to predict the species' physical properties which could result in a risk ranking according to the severity of the product form to head loss. The basis for the calculations within these computer programs is usually a database of temperature-dependent reaction coefficients for the numerous reactions that may be possible for the multiple constituents that are available. In order to produce correct results, the database must contain reaction coefficients for all the reactions that are possible, throughout the temperature range to which the constituents will be exposed. This can be occasionally difficult to ascertain, and a high level of knowledgeability on the part of the programmer is mandatory.

The great benefit of this relatively cheap and quantitative computational thermodynamic approach is that numerous (possibly hundreds of) thermal profiles, chemistries, and other conditions can be examined beforehand to constrain the experimental procedures prior to the more expensive, certainly time-consuming, and therefore limited amount of real-world testing that can be completed. These calculations can then be compared to the ORNL report data on TMI, or tables of physical properties (the Merck index or a similar compilation) to determine the plausibility of gel formation as a function of LOCA size and conditions.

Secondly, it may be possible to computationally (rather than experimentally) model the initial phase of a LOCA event – that phase during which the containment pressure may be elevated and

some containment -constituents may be exposed to water/steam mixtures at temperatures greater than that corresponding to ambient pressure boiling. The objective of this consideration is to avoid having to construct an experimental test loop capable of operating at elevated temperature and pressure. If the reaction products evolving from that brief, initial phase of the LOCA event can be determined calculationally, instead of experimentally, the cost and time savings will be significant.

References 4 and 5 contain tables showing that pool temperature never exceeds ambient boiling for any LOCA size or location. However, containment temperatures may be greater than 212°F for short periods of time (several minutes or less). The equilibrium chemistry computations should examine whether important chemical species could develop during these brief, but possibly important transients. Near the location of the breach, steam jets may dislodge and possibly react with degrading structural components. The products of these possible reactions should also be taken into account. The products of this reaction may either be used as part of the initial reactant charge for the loop tests to follow, or the reaction may be replicated in the test loop, by conducting the test at a lower, more easily achievable temperature, for a correspondingly longer time, based on an Arrhenius-type calculation. Based on the chemical equilibrium calculations, a time-temperature profile of each test will be constructed, along with the evolving chemical speciation. Since not all possible species would be available at $t = 0$ seconds, each test plan should include a timing scheme for addition of individual reactants to the solution.

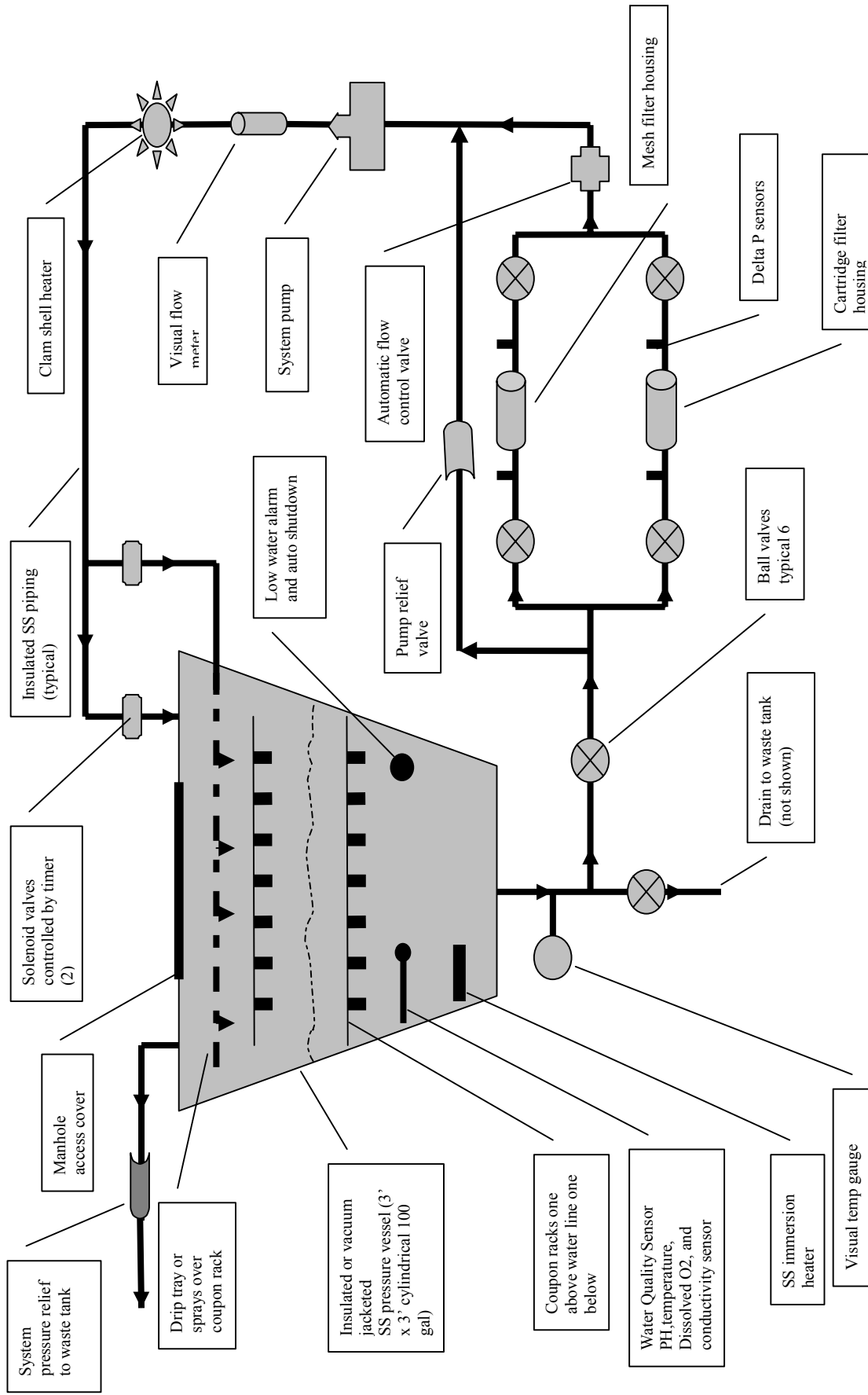
It is possible that even an exhaustive exercising of the chemical equilibrium program will produce no useful guidance about gelatinous reaction products. In this case, the design of the experiments will be based on the LANL results, [6] and the TMI findings [2] together with plausible extension of these results. All test plans must be approved, in advance of test initiation, by the NRC and industry program managers.

Phase 1B: Assembly of Water Loop Test Facility

During the time necessary to complete the appropriate chemical equilibrium calculations, A test facility should be constructed, or modified, for the purpose of conducting a series of relatively short-term (30 days or less) experiments to demonstrate whether a gel will form, and whether it will exacerbate sump strainer debris accumulations.

A schematic of a suitable test loop is shown as Figure 1. The facility will have the following characteristics:

1. The overall volume of the system should be approximately 100 gallons (or more) in order to achieve concentration levels sufficient to produce useful quantities of the reaction products that are sought by this test plan. In part, the volume of the system will depend on the results of the chemistry equilibrium calculation. If the quantities of gelatinous reaction products predicted by the calculations are small, a proportionately larger system volume will be required. The chemical constitution of the solution in the loop will simulate that found in the containment pool, following a LOCA. This solution will contain boric acid, lithium hydroxide, and a pH



System Operation

Pump runs continuously and flow control valve maintains flow even as the filters cartridge plugs. If plugging becomes excessive the pump pressure relief valve will open to protect the pump.

The tank heater and clam shell heater will have automatic controllers that respond to the temperature signal from the water quality sensor. Delta P sensors, and water quality sensor will have continuous recording to a data logger and/or computer hard drive.

The low-water alarm float valve will shut down the pump and heaters. The float will be above the immersion heater in the tank.

controlling agent (either TSP or sodium hydroxide, as required by the Phase 1 calculations). The pH of this solution will be in the range of 7.0 to 8.5.

2. The system will be capable of maintaining the aqueous environment at a temperature closely approaching 100°C, continuously for a period of 30 days. The system capabilities will include instrumentation sufficient to monitor water quality for pH, temperature, conductivity, or other parameters. The temperature control for the system will allow programming such that temperatures may be reduced, as a function of time, to simulate the cooling of the containment pool over a period of tens of hours.

3. The system will accommodate a number of immersed sample coupons, representing the various sources of chemical species. These coupons might include galvanized steel plates, aluminum extrusions, concrete, painted surfaces, or other potential reaction constituents that were predicted by the Phase 1 modeling.

4. The system will accommodate a rack of sample coupons subject to spray of water that simulates the chemistry of a containment spray system. The object of this aspect of the system is to evolve the reaction components that may be produced by the chemical and mechanical action of the containment spray system. Provision must be made for frequent, visual inspection of the spray rack, and for replacement of coupons that have been exhausted by the spray process.

5. The system will be capable of water circulation at rates that simulate a sump return flow rate per unit area of the sump strainer.

6. The system will have a side loop, containing a mesh filter that simulates a sump strainer; the areal size of the filter will be proportioned to match the volumetric flow rate such that the linear flow rate approximates the expected recirculation rate during an ECCS transient. The strainer in this loop will have the facility to accept “mattes” of fibrous and particulate materials to simulate the sump strainer blockage that is predicted typically.

7. The simulated sump solution will be pumped through the mesh filter loop at a linear flow rate of 0.3 ft./sec. The system pressure on both sides of the filter will be continuously monitored, and head loss computed from this data.

8. Following each test, the mesh filter will be examined optically and microscopically for evidence of the mechanism of flow blockage.

In addition to the test facility itself, provision must be made to complete batch sample chemical analysis of the reaction products in a matter of a few hours, in order to accurately and promptly obtain confirmation that the reaction is proceeding, or approaching equilibrium.

Phase 2: Conduct of Tests

The objective of the first test in this series is to evaluate the time required for the recirculating solution to reach a steady state in the chemical reaction and product deposition process. It is anticipated that the chemical reaction among the zinc-aluminum-calcium silicate components may require many tens of hours, or days. This initial test will incorporate the proportions of constituents deemed most likely to produce a gel, as predicted in the Phase 1A process. The test will continue for 30 days, or less, if the gel forms earlier. If the test reaches a chemical steady state, as determined by the on-line instrumentation, together with batch sample analysis, the test may be terminated before the 30-day requirement is achieved.

The objective of subsequent tests will be to maximize the contribution of the gelation production on the head loss at the simulated sump strainer. These tests will be conducted with a lower regard for replicating the LOCA time-temperature profiles, and a higher regard for optimizing the chemical reactions. In other words, certain chemical constituents that might evolve later in the LOCA event could be added at $t = 0$ for the test. Another possibility is that chemical reaction rates (or precipitation rates) may be sped up by conducting the test at a higher (or lower, respectively) temperature than the RELAP5 code might predict.

References:

1. NRC Web Site: <http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html>
2. ORNL Analytical Results for the TMI Containment Water September 14, 1979
3. Announcement of Workshop on Debris Impact on Emergency Coolant Recirculation, to be held February 25 – 27, 2004, Los Alamos National Laboratory; details at <http://www.nea.fr/html/nsd/workshops/debris/>
4. GSI-191: Thermal-Hydraulic Response of PWR Reactor Coolant System and Containments to Selected Accident Sequences, NUREG/CR-6770, August 2002.
5. Knowledge Base for the Effect of Debris on Pressurized Water Reactor Emergency Core Cooling Sump Performance, NUREG/CR-6808, February, 2003.
6. Small-Scale Experiments: Effects of Chemical Reactions on Debris-Bed Head Loss, Los Alamos National Laboratory Report LA-UR-03-6415, November 2003.

Appendix A

Debris Generation and Transport Parameters:

LBLOCA, MBLOCA, & SBLOCA:

**Large Dry Containment
Ice Condenser Containment**

Table 1-1. Debris Generation and Transport Parameters: LBLOCA—Large Dry Containment

Parameter	Blowdown Phase			Injection Phase			Recirculation Phase		
	0+ s	20 s	45 s	45 s	15 min	27 min	27 min	2 h	24 h
RCS pressure at break (psia)	2250	393							
RCS temperature at break (°F)	531	291	250	250	173	144	144		
Break flow (lb/s)	7.97e4	1.28e4	4.89e3						
Break flow velocity (ft/s)	296	930	100						
Break flow quality	0	0.25	0.3	0.3	0				
Safety injection (gpm)				11500	11500	11500			
Recirculation flow (gpm)							17500	11800	11800
Spray flow (gpm)				0	5700	5700	5700	0	
Spray temperature (°F)					105	190	190		
Containment pressure (psig)	0	36	33		11.5	7	7	1.5	0
Containment temperature (°F)	110	305	250		190	163	163	115	95
Pool depth (ft)					2	3.5	3.5	3.5	3.5
Pool temperature (°F)					212	187	187	125	100
Pool pH									
Containment atmosphere velocity (ft/s)	282								
Containment relative humidity (%)	50	100	100	100	100	90	90	100	100
Paint temperature (°F)	100		215		240	220	220	145	112

Peak break flow: 7.97×10^4 lb/s at 0+ s

Quality at peak break flow: 0

Peak containment pressure: 36 psig at 20 s

Peak break flow velocity: 930 ft/s at 21 s

Quality at peak break flow velocity: 0.25

Peak containment atmosphere velocity: 282 ft/s at 0+ s

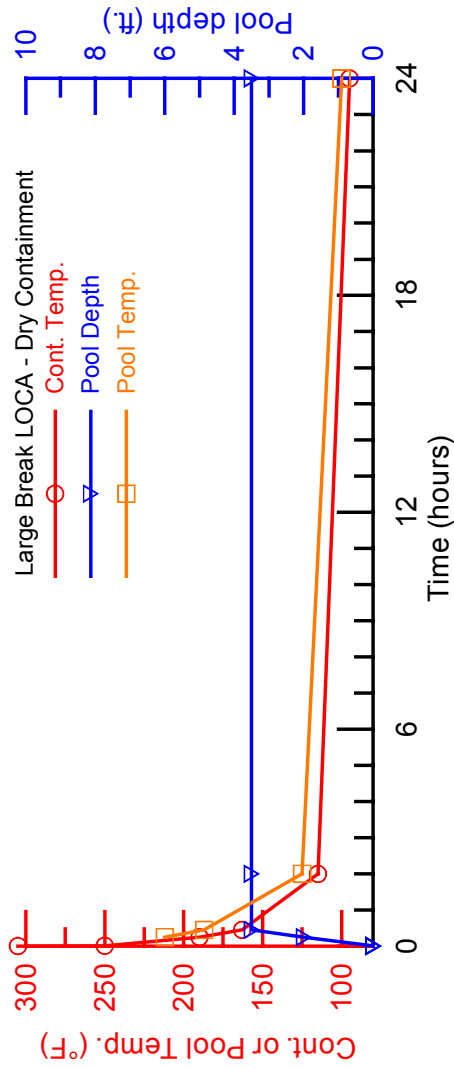
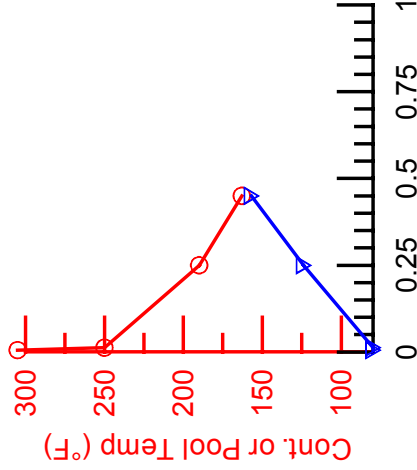
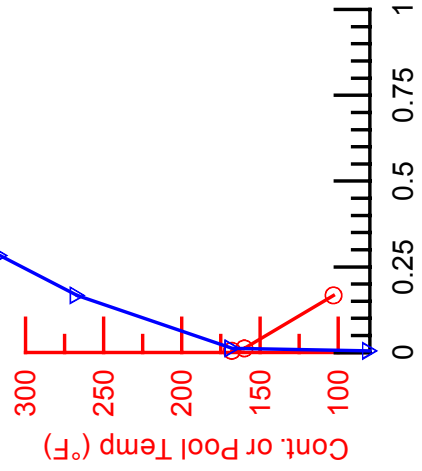


Table 1-2. Debris Generation and Transport Parameters: LBLOCA—Ice Condenser Containment

Parameter	Blowdown Phase			Injection Phase			Recirculation Phase		
	0+ s	20 s	45 s	45 s	10 min	17 min	17 min	2 h	24 h
RCS pressure at break (psia)	2250	393	55						
RCS temperature at break (°F)	531	291	250	250	200	160	160		
Break flow (lb/s)	7.97e4	1.28e4	4.89e3						
Break flow velocity (ft/s)	296	930	100						
Break flow quality	0	0.25	0.3	0.3	0				
Safety injection (gpm)				11500	11500	11500			
Recirculation flow (gpm)							18000	18000	18000
Spray flow (gpm)				6400	6400	6400	6400	6400	6400
Spray temperature (°F)				105	105	97	97	95	89
Containment pressure (psig)	0+	14	10.1	10.1	4.5	4.5	4.5	3	2
Containment temperature (°F)	100	168	160	160	103	105	105	98	100
Pool depth (ft)				4	8.5	10.75	10.75	10.8	10.1
Pool temperature (°F)				180	157	159	159	148	126
Pool pH									
Containment atmosphere velocity (ft/s)	184	18	1						
Containment relative humidity (%)	0	50	100	100	80	96	96	97	98
Paint temperature (°F)	100	106	112	112	113	112	112	90	90

Peak break flow: $7.97 \times 10^{+4}$ lb/s at 0+ s
 Quality at peak break flow: 0
 Peak containment pressure: 14.4 psig at 15 s



Peak break flow velocity: 930 ft/s at 21 s
 Quality at peak break flow velocity: 0.25
 Peak containment atmosphere velocity: 184 ft/s at 0+ s

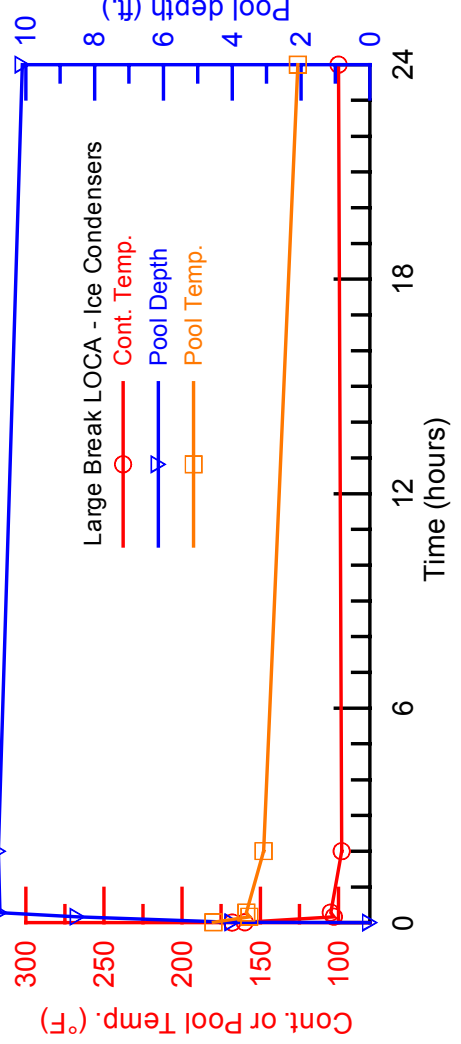


Table 2-1. Debris Generation and Transport Parameters: MBLOCA—Large Dry Containment

Parameter	Blowdown Phase				Injection Phase			Recirculation Phase		
	0+ s	30 s	180 s	20 s	15 min	57 min	57 min	2 h	24 h	
RCS pressure at break (psia)	2250	900	508							
RCS temperature at break (°F)	537	521	392		330	274	274			
Break flow (lb/s)	4940	1670	1000							
Break flow velocity (ft/s)	510	190	108							
Break flow quality	0	0	0		0.03	0.03	0.03	0		
Safety injection (gpm)				885	2500	2500				
Recirculation flow (gpm)							8250	2550	2550	
Spray flow (gpm)		0	5700		5700	5700	5700	0		
Spray temperature (°F)			105		105	150	150	150		
Containment pressure (psig)	0	6	9.5		5	3	3	4.2	1.5	
Containment temperature (°F)	110	170	182		160	140	140	148	120	
Pool depth (ft)					0.9	3.3	3.3	3.3	3.3	
Pool temperature (°F)					170	145	145	147	125	
Pool pH										
Containment atmosphere velocity (ft/s)	35	10	5							
Containment relative humidity (%)	50	100	100		98	98	98	98	100	
Paint temperature (°F)	110		160		175	160	160	155	121	

Peak break flow: 4940 lb/s at 0+ s

Quality at peak break flow: 0

Peak containment pressure: 10.2 psig at 2 min.

Peak break flow velocity: 510 ft/s at 0+ s

Quality at peak break flow velocity: 0

Peak containment atmosphere velocity: 35 ft/s at 0+ s

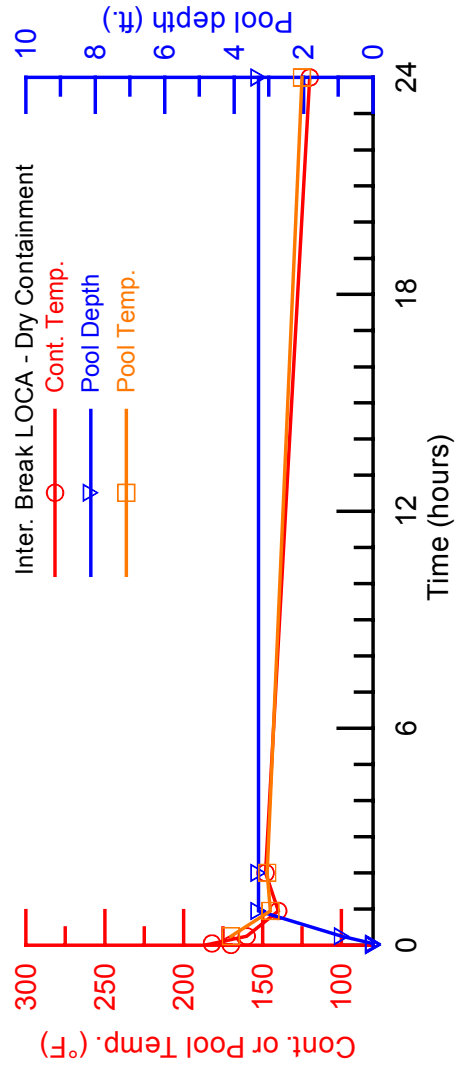
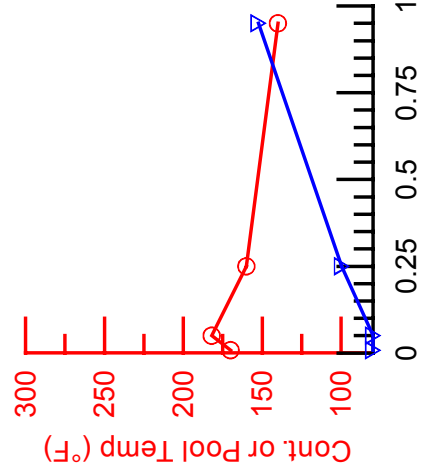


Table 2-2. Debris Generation and Transport Parameters: MBLOCA — Ice Condenser Containment

Parameter	Blowdown Phase				Injection Phase			Recirculation Phase		
	0+	30 s	180 s	20 s	15 min	57 min	57 min	2 h	24 h	
RCS pressure at break (psia)	2250	900	508							
RCS temperature at break (°F)	537	521	392		330	300	300			
Break flow (lb/s)	4940	1670	1000							
Break flow velocity (ft/s)	510	190	108							
Break flow quality	0	0	0		0.03	0.03	0.03	0		
Safety injection (gpm)				885	2500	2500				
Recirculation flow (gpm)							9000	9000	9000	
Spray flow (gpm)		0	6400		6400	6400	6400	6400	6400	
Spray temperature (°F)			105		105	105	92.5	86.5	84	
Containment pressure (psig)	0	9.8	7.8		4	4	4	1.8	1.4	
Containment temperature (°F)	100	145	151		110	110	110	87	90	
Pool depth (ft)					4	7.9	7.9	8	9.6	
Pool temperature (°F)					150	146	146	117	104	
Pool pH										
Containment atmosphere velocity (ft/s)	30	2.5	1.25							
Containment relative humidity (%)	0	10	40		80	97	97	97	98	
Paint temperature (°F)	100	101	125		130	125	125	95	90	

Peak break flow: 4940 lb/s at 0+ s

Quality at peak break flow: 0

Peak containment pressure: 11 psig at 55 s

Peak break flow velocity: 510 ft/s at 21 s

Quality at peak break flow velocity: 0.25

Peak containment atmosphere velocity: 30 ft/s at 0+ s

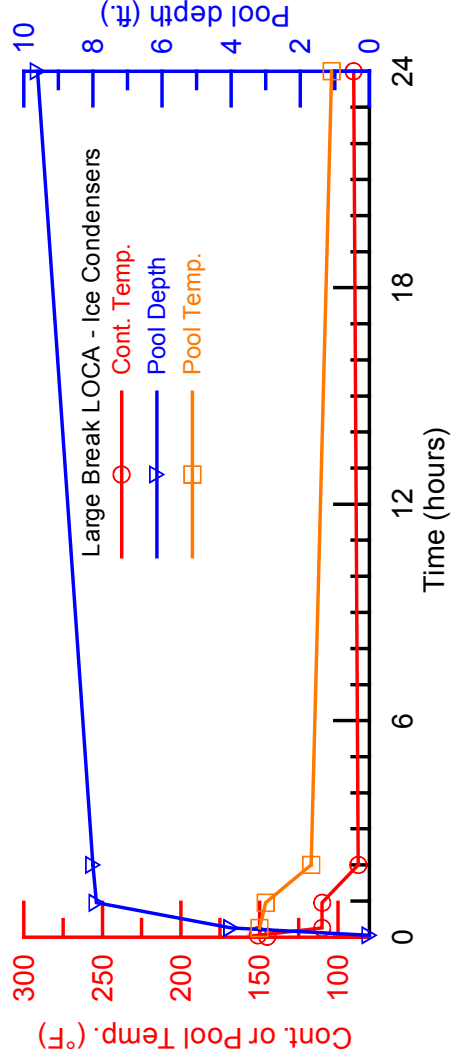
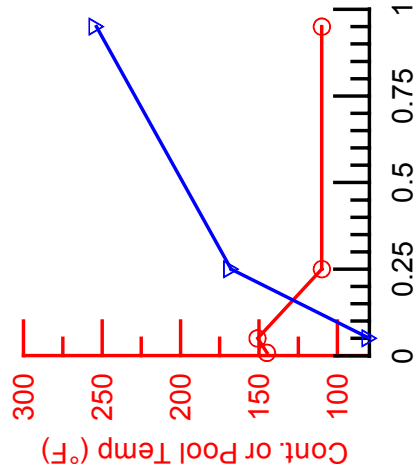


Table 3-1. Debris Generation and Transport Parameters: SBLOCA—Large Dry Containment

Parameter	Blowdown Phase			Injection Phase			Recirculation Phase		
	0+	30 min	1 h	60 s	2 h	3 h	3 h	12 h	24 h
RCS pressure at break (psia)	2250	605	512						
RCS temperature at break (°F)	538	354	371		270	236	236		
Break flow (lb/s)	550	343	300						
Break flow velocity (ft/s)	320	320	320						
Break flow quality	0	0	0						
Safety injection (gpm)				1500	2500	2500			
Recirculation flow (gpm)							2500	2500	2500
Spray flow (gpm)				Sprays Not Required					
Spray temperature (°F)									
Containment pressure (psig)	0	5	5		4	3		1	0.75
Containment temperature (°F)	110	160	160		150	140		115	110
Pool depth (ft)			0.8		1.5	2.25		3	3
Pool temperature (°F)			157		157	150		125	118
Pool pH									
Containment atmosphere velocity (ft/s)	9	4	4						
Containment relative humidity (%)	50	100	100		100	100		100	100
Paint temperature (°F)	100	160	160		157	153		127	117

Peak break flow: 550 lb/s at 0+ s

Quality at peak break flow: 0

Peak containment pressure: 6 psig at 38 min.

Peak break flow velocity: 320 ft/s at 0+ s

Quality at peak break flow velocity: 0

Peak containment atmosphere velocity: 9 ft/s at 20 s

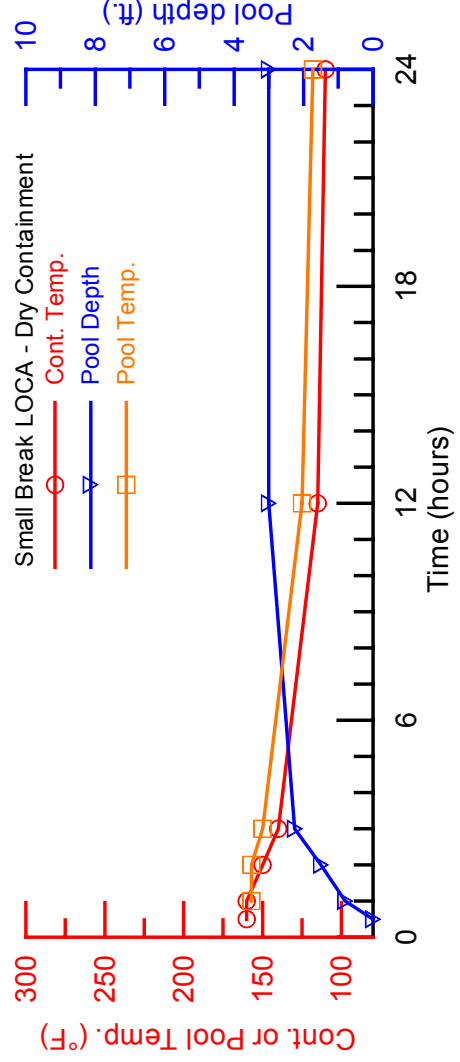
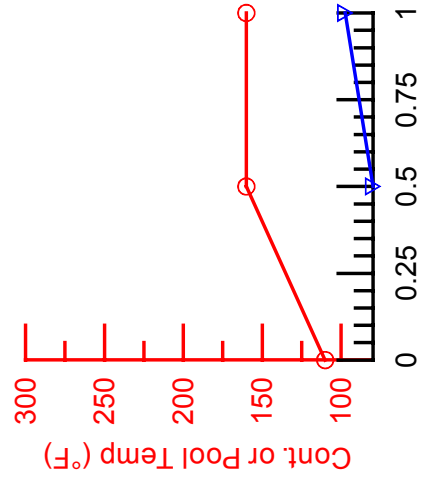


Table 3-2. Debris Generation and Transport Parameters: SBLOCA – Ice Condenser Containment

Parameter	Blowdown Phase			Injection Phase			Recirculation Phase		
	0+ s	30 min.	1 h	60 s	15 min	35 min	35 min	5 h	24 h
RCS pressure at break (psia)	2250	605	512						
RCS temperature at break (°F)	538	354	371		391	362	362		
Break flow (lb/s)	550	343	300						
Break flow velocity (ft/s)	320	320	320						
Break flow quality	0	0	0						
Safety injection (gpm)				1500	2500	2500			
Recirculation flow (gpm)							9000	9000	9000
Spray flow (gpm)		6400	6400	0	6400	6400	6400	6400	6400
Spray temperature (°F)		105	91		105	105	91	87.5	86
Containment pressure (psig)	0+	4.1	3.6	3.4	4.4	4.2	4.2	2.25	1.8
Containment temperature (°F)	100	111	96.5	94	112	110	110	92	95
Pool depth (ft)		5.5	6.75		2.5	6.5	6.5	9	8.9
Pool temperature (°F)		137	132		137	137	137	120	114
Pool pH									
Containment atmosphere velocity (ft/s)	2.9	0.7	0.7						
Containment relative humidity (%)	0	97	97	6	100	97	97	97	97
Paint temperature (°F)	100	110	104	100	106	110	110	92	96

Peak break flow: 550 lb/s at 0+ s

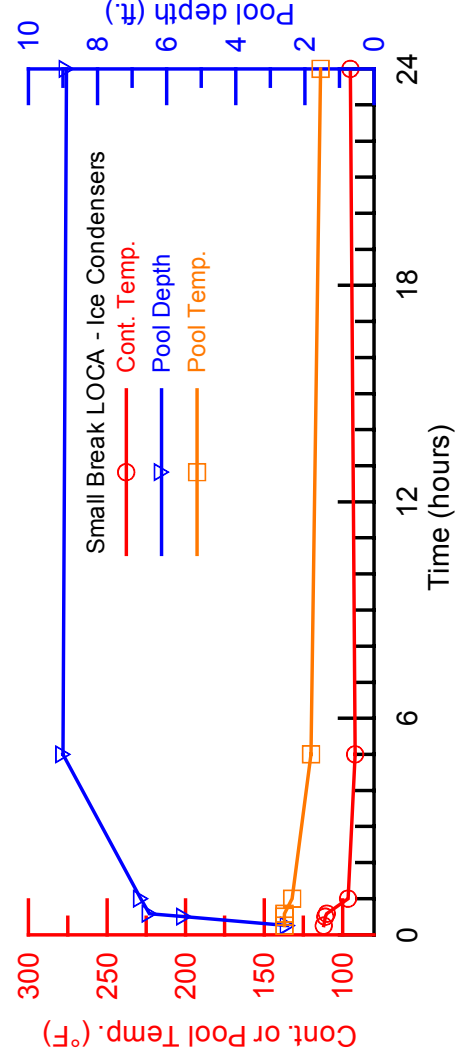
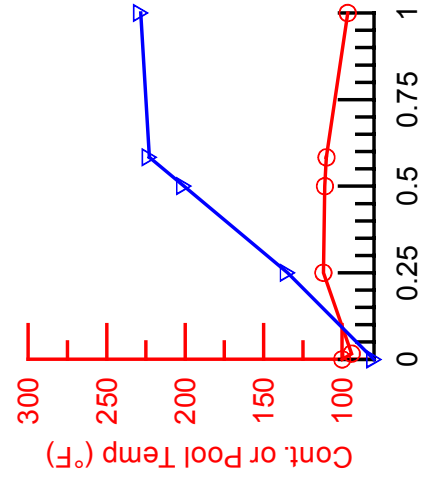
Quality at peak break flow: 0

Peak containment pressure: 4.4 psig at 15 min.

Peak break flow velocity: 320 ft/s at 0+ s

Quality at peak break flow velocity: 0

Peak containment atmosphere velocity: 2.9 ft/s at 23



Appendix B

Analysis of Containment Pool Water at 153 Days Following TMI-2 Incident, March 28, 1979

The analysis of the containment water was separated into three strata corresponding to the top, middle, and bottom of the containment water samples. Observations made by the Oak Ridge National Laboratory (ORNL) for the 3 distinct layers are shown in Table 1 with the compositional analyses in Tables 2 and 3. The data in Table 3 shows the very high levels of B and Na and to a lesser extent Al, Cl, Ca, Fe, K, Li, and S which are in the 1-15 ppm range. Interestingly, both Cu and Ni increase in concentration from the top/middle to the bottom solution, i.e. from ≤ 0.2 ppm to 10 and 3 ppm, respectively. A greenish, flocculent, gelatinous material was also found to precipitate at the bottom of the containment walls and was analyzed. The chemical analyses indicate that the majority impurity constituent in the gelatinous solid was Cu at 54ppm followed by Ni and Fe at 10ppm and Al (8ppm), Mg (7ppm), S (5ppm), B (3ppm), Ca (2ppm), Cr(2ppm), and Zn (2ppm).

Table 1. TMI Containment Water Characteristics

	Location of Containment Water Examined		
	Top	Middle	Bottom
Visible Color	Clear - Light Yellow Tint	Clear - Light Yellow Tint	Green with Solid Precipitates
Visible Organic	None	None	None
Rad Level Side (mR/hr)	580	500	530
Rad Level Bottom (mR/hr)	740	780	800
Precipitate	None	None	Yes: Flocculent in appearance, gelatinous, dirty green color, 10% by vol., centrifuged to 4% by vol.
Volume (ml)	30	30	30
Dissolved Organic Carbon (ppm)	2-22	-	-

Table 2. TMI Containment Water Radiochemical Analysis ($\mu\text{Ci/ml}$)

	Top	Middle	Bottom
^{137}Cs	176	179	174
^{134}Cs	40	40	39.6
^{140}La	0.09	0.078	0.74
$^{89+90}\text{Sr}$	46.3	43.5	44.9
^3H	1.03	1.05	1.01
^{129}I	0.079 ppm	0.080 ppm	0.076 ppm
^{131}I	0.012	0.012	0.013
^{90}Sr	2.7	2.9	2.83

Table 3. TMI Containment Water Spark Source Mass Analysis (ppm)

	Top	Middle	Bottom
Ag	<0.5	<0.2	<0.3
Al	3	3	3
As	<0.2	<0.05	<0.1
B	1950	2200	1900
Cl	10	15	8
Ca	10	10	8
Cd	<0.2	<0.2	<0.2
Co	<0.1	<0.1	<0.1
Cr	0.7	0.7	0.7
Cs	0.6	0.7	0.7
Cu	≤0.2	≤0.2	10
Fe	0.58	1.1	1.8
I	<0.5	<0.5	<0.5
In	<0.1	<0.1	<0.1
K	4	4	4
Li	1.61	1.55	1.44
Mg	≤3.0	≤2.0	≤1.0
Mn	≤0.1	≤0.05	≤0.1
Mo	≤0.5	≤0.5	1
Na	1080	1200	1200
Ni	≤0.2	≤0.2	3
P	0.3	0.3	0.2
Rb	0.3	0.3	0.3
S	9	8	7
Sr	≤0.1	≤0.1	≤0.1
Te	<0.2	<0.5	<0.4
Ti	≤2.0	≤1.0	≤1.0
V	≤0.2	≤0.1	≤0.1
Y	≤0.4	≤0.1	≤0.1
Zn	0.5	0.5	0.4
U	0.007	0.013	0.028
Pu	0.00001	0.000011	0.000033

Table 4. Neutron Activation Analysis of Precipitates from Bottom TMI Containment Water

Solids from Bottom Containment Water (ppm based on total volume of bottom sample)	
²³⁵ U	0.00459
In	0.16
¹²⁹ I	0.07
Cu	54
Mn	0.62
Al	7
Ca	≤2.0

Table 5. Spark Source Mass Analysis of Precipitates from Bottom TMI Containment Water

Solids from Bottom Containment Water (ppm based on total volume of bottome sample)	
Ag	8 ^a
Al	8
B	3
Ca	2
Cd	<0.5
Co	<0.1
Cr	2
Cs	<0.5
Cu	54 ^b
Fe	10
I	0.7
In	0.3
K	1
Li	<0.3
Mg	7
Mn	1
Mo	<1
Na	<1
Ni	10
P	0.4
Rb	<0.3
S	5
Sr	<0.2
Te	<0.2
Ti	0.5
Zn	2
U	0.106 ^c
Pu	0.00016 ^c

^a May be some memory from a previous unrelated test/analysis, ^b From NAA data, ^c Thermal Emission Mass Resin Bead Analysis