August 16, 2005

WOG-05-370

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Subject: **Westinghouse Owners Group Report Evaluating Potential Safety Benefits of Redefining the Large Break Loss of Coolant Accident (LBLOCA) Design Basis Break Size in 10CFR50.46 (MUHP-3062)**

Dear Dr. Sheron:

The WOG appreciates the opportunity to provide input to the NRC regarding the potential safety benefits that can result from licensees implementing various plant changes that may be enabled by redefining the LBLOCA in 10CFR50.46.

The attached report provides results of an evaluation of two potential safety benefits that may be achieved by a redefined LBLOCA. The WOG agreed to evaluate these candidate benefits in a January 13, 2005 meeting with the NRC staff, who agreed to perform their own analyses. The WOG and NRC staff have separately performed detailed thermal-hydraulic analyses and obtained similar results. The quantification of the benefits is based on the results of these thermal-hydraulic analyses.

The WOG emphasizes that these are only two examples of potential safety benefits and do not define the scope and purpose of a revision to 10CFR50.46. We believe the rule change is required to establish the performance-based, risk-informed regulatory structure that will enable these and other safety and operational benefits. However, based on these two examples, it appears that redefining the LBLOCA would enable substantial safety benefits in terms of core damage frequency reductions.

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We welcome the NRC's LBLOCA design basis redefinition efforts and look forward to providing input to the NRC on the details of the rule change when the proposed rule is issued for comment. We believe the revised rule should include an uncomplicated, manageable process that better focuses resources on safety and facilitates application by licensees.

Please contact Mr. Wayne Harrison (STPNOC), Chairman of the WOG LBLOCA Redefinition Working Group, at 361-972-7298 with any questions or comments regarding this information.

Sincerely yours,

Steven M. DiTommaso for

Frederick P. "Ted" Schiffley, II
Chairman, Westinghouse Owners Group

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Attachment

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EVALUATION OF SAFETY BENEFITS OF LARGE BREAK LOCA REDEFINITION

1.0 INTRODUCTION

A risk-informed, performance-based option for 10CFR50.46 will establish the regulatory structure required to enable plant changes that will result in safety and operational benefits that are precluded or made unnecessarily difficult by the current regulatory requirements.

At the January 13, 2005 meeting between the Westinghouse Owners Group, the NEI Option 3 Task Force, and the NRC, it was agreed that the industry and the NRC would work in parallel to estimate the safety benefits for two example applications of LBLOCA redefinition. This report discusses results of the WOG quantification of safety benefits for two example applications of the proposed rule change. The WOG and NRC staff have independently performed thermal-hydraulic analyses related to the two example applications, compared results, and found the WOG and staff results to be in agreement.

These two example applications of LBLOCA redefinition are:

- Improved Emergency Diesel Generator (EDG) reliability resulting from elimination of the need for fast starts to support LOCA mitigation. The start time for the diesel generators is assumed to be extended from the current neighborhood of 10 seconds to 60 seconds.

- Delay or elimination of automatic containment spray actuation for LOCA results in delaying the need for sump recirculation for all LOCAs and may result in the ability to use alternate long term cooling options, such as shutdown RHR cooling, for small break LOCAs.

Detailed thermal-hydraulic analyses were completed for the two changes based on a 4-loop Westinghouse NSSS plant with a large dry containment. Due to the variability of contributors to risk amongst the PWR plants, the quantified safety benefits, in terms of change in risk, are estimated for a wide range of PWR plant designs.

There are other safety benefits that will be derived from the proposed rule change that are not as easily quantified as those chosen as example applications. These include improved focus on safety significant items, improved fuel management, and fewer plant shutdowns. The WOG emphasizes that these two applications are examples, and do not define the purpose of the proposed rule change. We believe the rule change is required to establish the performance-based, risk-informed regulatory structure that will enable these and other safety and operational benefits not yet identified.

2.0 SUMMARY OF RESULTS

2.1 Results from EDG Delay Evaluation

Rapid starts and loading of the Emergency Diesel Generators (EDGs) are currently required to support the safety analyses for large break LOCAs. For the double ended cold leg guillotine break with a coincident loss of offsite power, a rapid start of the EDGs is required to support the pumped safety injection flow requirements. Typically the EDGs must be started and the safety injection pumps loaded within about 10 seconds. If a LOCA with a coincident loss of offsite power is only required for break sizes less than the Transition Break Size (TBS), delayed starting and loading of the EDGs could be realized. The EDGs are periodically tested to assure that they can be started and loaded within a time prescribed in the each plant's Technical Specifications. Elimination of the rapid EDG start requirement should increase the reliability of the EDGs for more probable events where they are called upon to start and be loaded in a more relaxed time frame. Elimination of EDG failures due to rapid starts will also increase EDG availability as less corrective maintenance will be required.

The potential benefits associated with elimination of the fast start requirements for Emergency Diesel Generators (EDGs) as a result of re-defining the design basis loss of coolant accident have been investigated and quantified. Thermal-hydraulic analyses using approved safety analysis models show that for breaks smaller than the TBS, delaying the initiation of safety injection by as much as 60 seconds after the initiation of the LOCA would not result in unacceptable cooling of the core. In addition, the analysis shows that the currently limiting small break size remains limiting. It should be noted that the baseline plant design chosen for this study has historically shown considerable SBLOCA margins, and plants with lesser margins may not be able to accommodate a delay of this magnitude.

Containment analyses show that the potential effect of a 60 second diesel delay is on the order of a 1 psi penalty for the post blowdown/post reflood peak for the double ended guillotine break using the current safety analysis mass and energy releases. The use of more realistic models to predict the mass and energy releases would result in a considerably smaller peak pressure. The benefit in the peak pressure in going from the double ended guillotine break size to a transition break size as represented by an accumulator or surge line break is approximately 8 psi.

Loss of offsite power is typically modeled as the initiating event. The contribution of loss of offsite power to the core damage frequency shows a wide variation from plant to plant. A loss of offsite power induced by a reactor trip and starting of safeguards equipment is a very small contributor to core damage frequency and is normally screened out of the risk assessment. Therefore, the quantification of the benefits of eliminating EDG fast starts was performed for several plants to illustrate the range of possible benefits that might be realized as a result of the elimination of fast starts. It was found that the decrease in total core damage frequency from eliminating EDG fast start requirements ranges from as high as a 5% reduction to as little as a 0.1% reduction, depending upon plant specific vulnerabilities to loss of offsite power events.

2.2 Results from Containment Spray Delay Evaluation

One of the insights from the plant specific PRA assessments is the importance of the operator action to switch to sump recirculation for mitigation of LOCAs. Not automatically starting containment spray for a LOCA or delaying its actuation significantly reduces the rate of depletion of the Refueling Water Storage Tank (RWST) from which the Emergency Core Cooling System (ECCS) also takes suction. Reducing the rate of RWST depletion significantly extends the time that the operators have to switch the ECCS from taking suction from the RWST to taking suction from the containment sump. This additional time increases the likelihood for success of that action. Also, for small break LOCA sequences, the longer time until the ECCS must be switched to take suction from the containment sump permits cooldown and depressurization of the reactor coolant system to the point where normal shutdown cooling can be used as an alternative to ECCS recirculation from the containment sump.

The thermal-hydraulic containment analyses for the case of no automatic containment spray actuation show that, for transition size breaks, and smaller, the peak calculated containment pressure remains below the design pressure, even with less than perfect mixing in the containment. Operator action to initiate operation of the containment spray would be needed in the longer term for plants that do not have safeguards grade containment fan cooler units capable of removing decay heat from the containment. For breaks greater than the transition break size, up to and including the double ended guillotine break of a reactor coolant loop pipe, the use of current approved licensing models results in the predicted containment peak pressure that is about 12% above the current calculated peak containment pressure predicted for the case with sprays operating normally. However, use of best-estimate models for these breaks would likely result in containment pressures that are at or below the current calculated containment pressure analysis of record. Again, operator action to initiate operation of the containment spray would be needed in the longer term for plants that do not have safeguards grade containment fan cooler units capable of removing decay heat from the containment. For breaks larger than the transition break size, the proposed changes to 10CFR50.46 may allow the non-safety grade fan coolers to be credited.

The containment spray system also is credited with removal of airborne fission product activity from the containment atmosphere following a large break LOCA in which there is a significant release from the reactor core. This presumption of core degradation is unrelated to analytical projections of core damage and essentially assumes that there is no core cooling. An assessment of the impact of a delay in initiating containment sprays on the radiological consequences of the large break LOCA with core melt was made using the Alternate Source Term (AST) methodology. The assessment shows that the offsite doses would be increased by less than 9% as long as containment spray is manually initiated within 35 minutes of accident initiation for a plant that does not credit Leak-before-Break (LBB). For a plant that does take credit for LBB, this time is increased to 45 minutes after the event initiation since it is assumed that there is a ten-minute delay in the onset of fuel damage.

The quantification of the risk benefit from eliminating automatic actuation of containment spray was performed for several plants to illustrate the range of possible benefits that might be realized. It was found that depending upon plant specific contribution of LOCAs to the overall risk, that the

decrease in total core damage frequency from eliminating automatic actuation of containment spray ranges from as high as a 9% reduction to less than a 1% reduction. Plants that would benefit the most are some of the ice condenser plants and large dry containment plants with low containment spray actuation pressure.

2.2.1 Other Benefits

It is important to point out that there are additional benefits from delaying the actuation of containment spray that were not quantified. These benefits include:

- More RWST inventory would be available to be injected into the RCS for cooling the core.
- A reduction in the potential for the generation of debris outside of the break zone of influence and subsequent transport of all debris to the containment sump that can cause sufficient head loss that damages the pumps during ECCS recirculation.
- Higher available nominal pump suction head at the sump for ECCS pumps without the additional draw from the Containment Spray pumps.

These unquantified potential benefits may be more widely available if plants can demonstrate that the revised design basis event from the proposed rule change can be mitigated without containment spray or with substantially less containment spray flow.

3.0 EVALUATION OF BENEFIT OF EXTENDED DIESEL GENERATOR START TIME

The potential benefits associated with elimination of the fast start requirements for diesel generators as a result of re-defining the design basis loss of coolant accident have been investigated and quantified.

It is widely believed that by reducing the harshness of the testing that is routinely performed on the Emergency Diesel Generators (EDGs) and by extending the time in which an EDG must start when called upon to operate the reliability of the EDG will be improved. To validate this belief, the WOG conducted a review of industry operating experience for EDGs to estimate the potential improvement in EDG reliability and the potential improvement in plant risk.

Clearly, if EDG start/load time was extended, there could be some negative impacts to other accident scenarios, particularly LOCAs in the size range below the transition break size. The following section describes the analysis work performed to quantify this.

3.1 Loss of Coolant Analyses for Delayed Diesel Generator Start Time

To help quantify the impact of delayed EDG start/load time, a thermal-hydraulic analysis run matrix was developed cooperatively with the NRC staff. The WOG analyses were performed with the NOTRUMP and WCOBRA/TRAC codes while comparable NRC analyses were performed with the TRACE and RELAP-5 computer codes. Several cases were identified which could help quantify the impact of delaying Emergency Diesel Generator (EDG) start/load time. The study was done for a Westinghouse NSSS 4-loop plant with safety grade charging pumps. The run matrix is as follows:

- The current limiting small break cases including both a 3 and 4 inch equivalent diameter break size,
- A cold leg break at accumulator/SI connection, using the actual flow area of pipe with ECCS flow in the affected loop assumed to be spilling to containment,
- A cold leg break at accumulator/SI connection, using the actual flow area of pipe plus 20% with ECCS flow in the affected loop assumed to be spilling to containment (has same effect as varying C_d),
- A cold leg break at accumulator/SI connection, using the actual flow area of pipe minus 20% with ECCS flow in the affected loop assumed to be spilling to containment, and
- A hot leg break at pressurizer surge line connection, using the actual flow area of pipe. This break size also has additional cases which vary break flow by +/- 20%.

This matrix accomplishes the following:

1. Includes actual piping flow areas
2. Addresses NRC desire to look for "cliff effects" in vicinity of TBS
3. Demonstrates pressurizer surge line break performance

The WOG results demonstrate that an EDG start/load time delay of 60 seconds (as opposed to 10 or 12 seconds) can be successfully accommodated for the baseline plant under the design basis accident provisions of the redefined large break LOCA, without violating the ECCS acceptance criteria. Furthermore, the currently limiting small break size remains limiting. It is recognized that the baseline plant design has historically shown considerable SBLOCA margins, and plants with lesser margins may not be able to accommodate a delay of this magnitude.

As discussed above, the break sizes estimated to be near the Transition Break Size (TBS) were also analyzed. Because of their size, the hot leg and cold leg breaks considering the largest attached piping are non-limiting. This is because breaks in this size range typically have behavior that is beneficial to a LOCA that includes:

- A blowdown rate that allows core stored energy removal but does not deplete the whole vessel of liquid mass.
- The momentum changes in the flow for cold leg breaks in this size range typically are not large enough to cause flow reversal in the core with a corresponding dry-out point.
- Rapid monotonic depressurization that allows large quantities of ECCS flow to enter the RCS in a timely manner while simultaneously curtailing break flow.
- The surge line break further benefits because blowdown cooling flow is not retarded since there are no momentum changes other than flow acceleration in the normal direction. In addition, all accumulators inject along with all pumped ECCS flow.

As such, these transients demonstrate a relative benign behavior with little or no core uncovery. Appendix A provides detailed results of LOCA analyses.

3.2 Containment Analyses for Delayed Emergency Diesel Generator Start Time

The design and licensing of nuclear power plants require that the containment be analyzed for pressure and temperature effects. The LOCA mass and energy release and containment integrity response analyses are performed to demonstrate that the integrity of the containment, containment structures, and containment cooling systems are adequate to mitigate the consequences of a hypothetical LOCA such that the containment pressure or temperature results do not exceed the acceptance criterion. The containment safeguards systems must be capable of limiting the peak containment pressure to less than the design pressure.

The mass and energy release calculation assumes a complete loss of all offsite power coincident with the LOCA. Typically the limiting single failure is the failure of one of the emergency diesel generators, resulting in the loss of one train of safeguards equipment. The emergency diesel generators are actuated to provide power for the safety injection system. The combination of signal delay plus diesel delay and additional delays in starting the ECCS pumps results in the delivery of SI after the end of blowdown. The diesel generators are also actuated to provide power for the emergency containment cooling systems, such as the fan coolers and containment spray system. The combination of signal delay plus diesel delay and additional delays affect the start times of these cooling systems.

The double-ended hot leg breaks are sometimes limiting for containment pressure; however, this break has only a blowdown peak and the results would not be affected by a diesel delay. For this reason the Double-Ended Pump Suction (DEPS) break was chosen for this study as it will illustrate the containment pressure penalty of increased diesel delay. The base analysis is for a typical Westinghouse NSSS 4-loop plant with a large dry containment. For this base analysis the calculated peak pressure occurred during the blowdown phase and is 55.10 psia. The post blowdown/post reflood peak pressure is 58.49 psia; the containment design pressure is 74.7 psia. This base analysis considered a diesel delay of approximately 10 seconds.

The effect of a diesel delay of 60 seconds was investigated for the DEPS break, the surge line break, and the accumulator line break. The potential effect of a 60 second diesel delay is on the order of a 1 psi penalty for the post blowdown/post reflood peak for either a LBLOCA or the smaller breaks.

The benefit in the peak pressure in going from the LBLOCA break size to an accumulator line break is approximately 10 psi. The surge line break results in a blowdown peak lower by approximately 10 psi when compared to the DEPS blowdown peak. The comprehensive details of the analysis and results are presented in Appendix B.

3.3 Risk Evaluation for Delayed Diesel Generator Start Time

3.3.1 Fast Start Impact on EDG Reliability

The industry and NRC recognized that cold fast starts of diesel generators were a leading cause of diesel unreliability. The more frequently the surveillance test was performed, the more unreliable the EDGs became. The NRC issued Generic Letter 79-17 on April 18, 1979 which transmitted an advance copy of NUREG/CR-0660 to each licensee. NUREG/CR-0660, "Enhancements of Onsite Emergency Diesel Generator Reliability" identified the major problems and proposed corrective actions to improve diesel generator reliability. Subsequently, the NRC issued Generic Letter 83-14 on December 16, 1983 requesting licensee input regarding EDG reliability data and assessments. The NRC issued Generic Letter 84-15 on July 2, 1984, which gave guidance on improving EDG reliability by: reducing the number of cold fast start surveillance tests, establishing and reporting reliability goals for the EDGs, and describing the program for attaining and maintaining that reliability goal. The basis for the recommendations was the recognition that cold fast starts are outside the EDG manufacturers' recommendations (pre-lubrication and warm-up before loading) and that such starts result in premature diesel engine degradation. These recommendations supported the resolution of Unresolved Safety Issue (USI) A-44, Station Blackout. On April 22, 1985, the NRC issued Generic Letter 85-32 to alert licensees of continued diesel engine failures (at three different sites). This generic letter stressed the importance of implementing the recommendations in Generic Letter 84-15. On March 13, 2001, INPO issued Significant Event Report SER 2-01 related to a significant diesel generator failure in late 2000. In this instance, although accelerated wear had been a recognized problem for EDGs used in standby applications, important engine parameters that can provide symptoms of accelerated wear were not effectively monitored or trended by the station.

In addition to the failure mechanisms and causes reported in the literature, discussions were held with industry EDG engineers at several plant sites. These discussions confirmed that fast starts, even following the best available current practices, are detrimental to EDG reliability and availability. These detrimental effects manifest themselves in failure of the EDG to start as well as failure to run, given that the EDG started successfully. Typically, causes of such failures include mechanical faults with the speed governor or inadequate fuel delivery to the fuel injectors. Fuel related problems are typically caused by air in the fuel supply lines, fuel rack linkage problems, and sticking/binding of fuel racks. When the surveillance test starting time criterion is not met, the surveillance test is immediately terminated and the affected EDG is taken out of service to diagnose the cause of failure and to make the necessary repairs before restoring the EDG to operability. Failure to meet the starting time criterion impacts the EDG basic events that represent "failure to start" and "unavailability due to corrective maintenance" which are included in the plant's PRA model.

During a fast start surveillance test, the EDG is subject to the following detrimental effects.

Rapid Temperature Change – This causes thermal shock and rapid differential thermal expansion of the cylinder liners and pistons. This type of thermal transient results in scuffs on the cylinder liners and piston skirts and may also cause hot spots in the combustion chamber.

Flooding of Cylinders – A significant amount of fuel is injected into the cylinders during fast start. The excessive quantity of fuel dissolves the lubricant on the cylinder liners and causes excessive wear on the cylinder liners and piston rings.

Reduction in Lubricating Properties – The wear on the cylinder liners reduces the porosity and the ability for the cylinder liners to retain oil for lubrication.

Rapid Loading – When the EDG load is increased to 100 percent over a short time span, the differential thermal expansion and excessive mechanical stresses on engine components cause excessive wear because there is not sufficient time to reach equilibrium temperature.

Poor Combustion – Combustion of the excess fuel injected into the cylinders is very inefficient, leads to carbon loading in the combustion chamber and downstream components such as the turbochargers.

The detrimental effects of excessive wear and tear on the EDG can be eliminated by allowing more time for EDG start, more gradual speed increase and/or more gradual loading of the EDG. The increased time for starting the EDG should eliminate start failures outside the current starting time requirement and improve overall EDG reliability and availability.

3.3.2 Results of EDG Failure Experience Review

The industry EDG failure experience was reviewed to quantify the potential safety benefits resulting from changing the start time for the EDG. The operating experience review consisted of a detailed assessment of the reported diesel generator failures obtained from the INPO EPIX database. Only those EDG failures that occurred from 1996 through 2004 were included in the

assessment in an attempt to reflect the most recent failure experience. The 1996 starting point was meant to reflect the changing practices in EDG operation and condition monitoring. A total of 603 failure events were reported for the period of interest.

The review identified 276 events involving failures of EDGs to run. Nine (9) of these failures impacted EDG long term reliability and were attributed to fast starts as shown in Table 3.3-1. Based on these values, 3.26% of the events involving failure of EDG to run can be attributed to fast starts. Similarly, 249 events involving failures of EDG to start were identified. Thirty-one (31) of these events involved failed surveillance tests (see Table 3.3-1). In almost all cases, the surveillance test failed because the prescribed starting time requirement was not met, but the EDG started and was judged to have been in a state where it could have been loaded. Thus, 12.45% of the events involving failure of EDG to start are attributed to fast starts.

The last three years of EDG operating experience were used to estimate the out-of-service hours for corrective maintenance due to fast start related failures. This period reflects current operating and maintenance practices in place at the plants to address the implementation of the Maintenance Rule. Sixteen EDG events attributed to fast starts were identified during this time period. These sixteen events resulted in the affected EDGs being taken out-of-service for 2,532 hours. One hundred fifty-seven EDG events (fast starts and other contributors) were identified during the three year window of operating experience. All these events resulted in the affected EDGs being taken out of service for 10,451 hours. Based on the out-of-service hours, these sixteen fast start failures contributed 24.23% to the unavailability of the EDGs due to corrective maintenance. That is, if fast starts were not practiced, it is estimated from available data that the corrective maintenance would have been reduced by 24.23%. Note that the overall maintenance unavailability used in PRA analyses consists of unavailability due to corrective maintenance (correcting failures) and unavailability due to periodic maintenance (e.g., inspections and maintenance prescribed by the diesel manufacturer).

The review did not identify any EDG event as a complete Common Cause Failure (CCF). An incomplete or partial CCF event is an insignificant contributor to CCF parameters. Since CCF parameters along with independent failure probabilities are used to estimate CCF probabilities, it was concluded that the percentage reduction in CCF parameter values would be insignificant. Therefore, no reduction in CCF parameter values (e.g., beta factors) was made in assessing the impact on Core Damage Frequency (CDF).

Table 3.3-1: EDG Failures Attributed to Fast Starts

Date	Failure
	Fail to Run Failures
07/10/96	Failure of pinion gear pin due to overstress
05/31/98	Failure due to sticking of exhaust valve caused by breakdown of lubrication properties
10/02/99	Failure due to fatigue failure of cylinder exhaust valve
12/01/00	Failure due to scoring and transfer of metal onto cylinder liner caused by excessive wear
10/16/02	Failure due to abnormal or accelerated wear
02/13/03	Failure due to abnormal or accelerated wear of metallic parts
06/18/03	Failure due to insufficient lubrication
09/15/03	Failure due to stress relaxation of cylinder liner adapter copper gasket(s)

Table 3.3-1: EDG Failures Attributed to Fast Starts	
Date	**Failure**
12/09/03	Failure due to destruction of EDG cylinders indicative of fracture caused by cyclic fatigue
Fail to Start Failures	
08/27/97	Failure due to faulty voltage regulators. EDG did not reach rated rpm & v on auto start.
01/13/98	Failure due to speed switch failed on demand. EDG did not reach rated rpm & v on manual start
01/14/98	Failure due to cyclic thermal stresses
03/29/98	Failure due to high stress or loading of EDG fan
04/01/98	Failure due to air flow restriction caused by loose mounting nut affected the interlock valve
05/02/98	Failure due to governor failed to control with degraded input signal
09/02/98	Failure due to fuel delivery. EDG tripped during manual loading & warm-up.
03/07/99	Failure of starting air system electrical process. EDG did not reach rated rpm & v on manual start
09/16/99	Failure of governor due to erratic operation of time delay relay
10/27/99	Failure cause inconclusive, possible faulty starting air system
11/04/99	Failure due to drift in speed setting of governor motor-operated potentiometer
11/16/99	Failure due to maintenance, mis-alignment / mis-adjustment of governor fuel rack linkages. EDG did not reach rated rpm
03/11/00	Failure due to loss of control from sporadic failure of governor, fuel, and logic circuit system. However, it did restart and worked fine.
06/29/00	Failure cause not specified, but Tech Spec start time not met.
12/21/00	High voltage transient cracked blocking diode semiconductor
01/28/01	Failure due to mechanical process, loose or under-torqued speed governor
04/23/01	Failure due to wear. EDG wrist pins failed due to improper lubrication
06/01/01	EDG did not reach rated rpm & v on auto start. Relay 15 failed to close.
07/05/01	Failure due to fuel header loss of prime.
01/11/02	Failure due to electrical process, calibration/setpoint drift.
02/11/02	Failure due to air start motors did not operate as expected
06/03/02	Failure due to solenoid valves for air start motors did not operate as expected
06/19/02	Failure due to right-side fuel rack binding
07/31/02	Failure due to suspected air in fuel system
11/02/02	Failure due to electrical process, relay failed to control. EDG operated, but not within specified parameters.
11/06/02	Failure due to sticking fuel racks
11/11/03	Increased in time delay of relays resulted in slow closing of EDG output breaker
12/07/03	Failure due to broken fuel injection hold clamp on cylinder caused by high cycle/low stress fatigue
01/20/04	EDG fails to start within 7 minutes due to lack of fuel oil after replacement
08/18/04	Failure due to fatigue failure of fuse in excitation circuit due to accelerated degradation
09/01/04	Binding of metering rod on 9L fuel pump

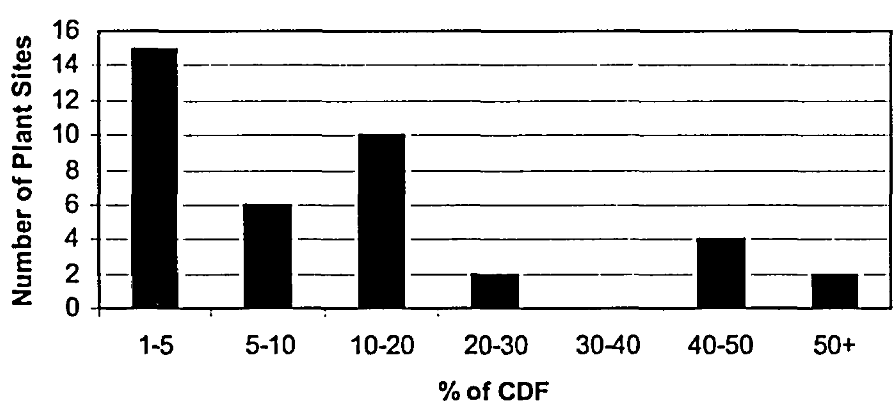
In summary, the data suggest that 3.26% of the EDG failure-to-run failures and 12.45% of the fail-to-start failures could be attributed to previous fast starts of the diesel during surveillance testing.

In addition, the corrective maintenance due to these EDG failures represents 24.23% to the total unavailability of the EDGs due to corrective maintenance. The reduction in overall maintenance unavailability must consider the split between corrective maintenance and preventive maintenance for the EDGs.

3.3.3 Impact of EDG Reliability Improvement to Plant Risk

The changes in EDG reliability derived from the failure data as discussed in the previous section were used to change the basic event failure probabilities for EDGs in the PRA. A review of the contribution of loss of offsite power to the overall Core Damage Frequency (CDF) shows a wide variation from plant to plant, as illustrated in Figure 3.3-1, below. Therefore, a number of different plants were chosen for the quantification of the reduction of CDF to illustrate the range of possible benefits that might be realized.

Figure 3.3-1
Distribution of Contribution to CDF from Loss of Offsite Power



Plant A

For Plant A, the overall CDF is 6.08E-05 per year with 61.7% of the total CDF due to loss of offsite power. The PRA basic event probabilities for EDG fail to start and fail to run were adjusted according to the findings from the fast start assessment described above. For Plant A, the maintenance unavailability split between corrective and preventive maintenance is not known. As a result, corrective maintenance was studied parametrically assuming that corrective maintenance accounts for 30%, 50% and 70% of the total maintenance unavailability.

The contribution to CDF from each of the EDG failure basic events for Plant A is shown in Table 3.3-2. The values presented in Table 3.3-2 represent the contribution to the total CDF from cutsets involving the basic failure. For some cutsets, more than one EDG failure mode is represented (e.g., EDG "A" fail to run; EDG "B" in maintenance). Thus the sum of the contributions from

each failure mode represents more than the total contribution to the overall CDF from EDG failures. However, the results in the table illustrate the relative importance of each failure mode. From the results presented in Table 3.3-2, it is seen that random EDG fail-to-run failures dominate the EDG failure contribution to CDF while EDG fail-to-start failures do not account for a significant contribution to the overall CDF. Therefore reductions in the fail-to-run failure rate will show the greatest benefits while reductions in the fail-to-start failure rate will not be as noticeable in the final results.

Table 3.3-2: Plant A EDG Failure Contributions to Overall CDF

Basic Event	% of Total CDF (1)
EDG Random Fail to Start	3.5
EDG Common Cause Fail to Start	0.9
EDG Random Fail to Run	36.9
EDG Common Cause Fail to Run	16.2
EDG Maintenance Unavailability	16.6
EDG Testing Unavailability	0.9
(1) The total % is greater than the contribution of loss of offsite power to the total CDF due to more than one failure mode represented in some cutsets	

The change in CDF for each of these assumptions is provided in Table 3.3-3. Since the contribution of corrective maintenance to the overall maintenance unavailability could not be determined for this plant, three cases of the corrective maintenance contribution were assessed to illustrate the difference that this assumption would make.

An additional case was assessed to determine the impact of not crediting a reduction in fail-to-start failures or changes in EDG maintenance unavailability due to fast starts. The basis for this case is that in plant PRAs, the basic event probability for EDG fail to start may have already accounted for EDG surveillance test failures in which the EDG started and could have been loaded as a success state. In determining the plant specific maintenance unavailability, these same failures may have already been screened from the unavailability hours.

As shown in Table 3.3-3, the results are somewhat sensitive to assumed split between corrective and preventive maintenance for the overall maintenance unavailability.

Table 3.3-3: Plant A Change in CDF for Various Cases

Case	Overall CDF (per year)	% Change
Present PRA Model	6.08E-05	-
Improvements FTS, FTR and MU / 30% Corrective Maintenance	5.85E-05	3.8%
Improvements FTS, FTR and MU / 50% Corrective Maintenance	5.80E-05	4.6%
Improvements FTS, FTR and MU / 70% Corrective Maintenance	5.76E-05	5.3%
Improvement in FTR Only	5.89E-05	3.1%

Plant B

For Plant B, the overall CDF is 2.74E-05 per year with 4.5% of the total CDF due to loss of offsite power. The assumed changes in EDG failure probabilities were based on an early assessment of the reductions in reliability. In this case, a 4.5% reduction in the fail to start failure probability (as opposed to a 12.54% reduction derived from the data analysis described above) and a 3.26% reduction in the fail to run failure probability were assumed. The 24.23% reduction in corrective maintenance unavailability, as derived in this report, was used with a 50%/50% split between corrective and preventive maintenance. The reduction in CDF is 2.0E-07 per year, which represents a 0.7% change.

Plant C

For Plant C, the overall CDF is 3.68E-05 per year with 14% of the total CDF due to loss of offsite power. It is noted that 11% of the total CDF is due to a loss of offsite power caused by internal flooding. Using the same changes in EDG failure probabilities discussed above for Plant B, the reduction in CDF was found to be 3.9E-07 per year, which represents a 1.1% change.

Plant D

For Plant D, the overall CDF reported in their current PRA is 1.71E-05 per year. Plant D is a dual unit station with capability to cross tie the EDGs between the two units and also has an alternate power supply from the switchyard of a nearby combustion turbine plant. The contribution to the total CDF from a single unit due to a single unit loss of offsite power initiating event is about 8%, while a dual unit loss of offsite power contributes about 2.5%.

The basic event probabilities for EDG fail to start and fail to run were adjusted according to the findings in this report. For Plant D, the portion of the maintenance unavailability due to corrective maintenance, as derived from data from 2000 to 2004 was found to be 9.47%.

The results of the re-quantification of the PRA model with the reduced basic event failure rates due to elimination of fast start EDG failures show a CDF decrease of 4.0E-08 per year or a 0.2% decrease in the CDF.

Since this plant configuration may be unique in term of alternate offsite power supplies, several sensitivity analyses were performed to illustrate the potential benefits of improving EDG reliability by eliminating the fast start requirements.

In the first sensitivity case for Plant D, only credit for cross-tying the alternate units EDGs was credited; the alternate power source from the nearby combustion turbine unit was taken out of the model. In this case, the baseline CDF was 1.90E-05 per year. In this case, the improvement in the basic event probabilities for the EDGs resulted in decrease in the CDF of 1.0E-07 per year, or a 0.5% decrease in CDF.

The second sensitivity case for Plant D involved eliminating the ability to cross-tie the diesel generators between the two units in addition to removing the alternate power source from the nearby combustion turbine unit from the model. This would be representative of a single unit plant or a dual unit plant with complete separation of the units. In this case, the baseline CDF was 3.16E-05 per year. In this case, the improvement in the basic event probabilities for the EDGs resulted in decrease in the CDF of 5.5E-07 per year, or a 1.7% decrease in CDF.

For Plant D a third sensitivity analysis was performed to study the impact of not crediting a reduction in the fail-to-start failures due to fast starts. If Plant D PRA model is re-quantified with no credit taken for reduction in the basic event probability for fail-to-start, the reduction in CDF for the case of all alternate sources of power is only 1.0E-08 per year, or a 0.1% decrease.

3.3.4 Summary

Loss of offsite power is typically modeled in PRAs as the initiating event. Loss of offsite power induced by a reactor trip and starting of safeguards equipment is a very small contributor to risk and is normally screened out of the risk assessment. The contribution of the loss of offsite power to the core damage frequency shows a wide variation from plant to plant. Therefore, the quantification of the benefits of eliminating EDG fast starts was performed for several plants to illustrate the range of possible benefits that might be realized as a result of the elimination of fast starts. It was found that the decrease in total core damage frequency from eliminating EDG fast start requirements ranges from as high as a 5% reduction to as little as a 0.1% reduction, depending upon plant specific vulnerabilities to loss of offsite power events.

For the double ended guillotine break with a coincident loss of offsite power and a delayed EDG start, some localized fuel damage could occur. However, the probability of wide spread core damage as a result of a double ended guillotine break of a coolant pipe combined with the probability of a coincident loss of offsite power is small enough to be screened from the PRA (e.g., less than 1E-08 per year).

4.0 EVALUATION OF BENEFIT OF DELAYED CONTAINMENT SPRAY ACTUATION

The potential safety benefits of delaying or eliminating the automatic initiation of containment spray was found to be dependent on plant-specific design characteristics. When actuated, containment spray results in a significantly faster draw-down of the refueling water storage tank water inventory that is also used for emergency core cooling. As a result, the transfer to emergency core cooling recirculation occurs much earlier than if spray were not operating. For plants requiring some manual actions to complete transfer to emergency core cooling recirculation, the benefits of delaying containment spray actuation until after transfer to emergency core cooling recirculation is completed can result in a decrease in plant risk as measured by the core damage frequency. Additionally, for small LOCA events without actuation of containment sprays, there would be sufficient time for the operators to cooldown and depressurize the RCS to enable the use of normal shutdown cooling. This provides an alternative long term core cooling method which should be credited in the PRA.

4.1 Containment Analyses for Delayed CS Actuation

A summary of the containment analysis is discussed in Section 3.2. Details are presented in Appendix B.

The effect of varying the delay in actuating containment sprays during the RWST injection phase was not investigated. However the effect of completely eliminating injection phase containment spray was investigated for the Double Ended Pump Suction (DEPS) break, the surge line break, and the accumulator line break.

Results show that there is approximately a 7 psi penalty in the peak calculated pressure for completely eliminating injection phase containment spray for the DEPS break and a 5 psi penalty for the smaller accumulator line break. Details are presented in Appendix B.

4.1.1 Offsite Dose Assessment for Containment Spray Delay

Redefinition of the large break LOCA has not been extended to include a redefinition of the analytical basis to be used for the determination of the radiological consequences of the event. Thus, the presumption of extensive core degradation must continue to be made.

The Alternate Source Term (AST) methodology presented in Regulatory Guide 1.183 was used to evaluate the impact of a delay in containment spray actuation on the large break LOCA offsite doses. The AST methodology includes a defined delay of 10 minutes before any activity is released from the core based on taking credit for Leak-Before-Break (LBB). Once fuel damage is initiated, there is a release of the fuel-clad gap inventory over a period of 0.5 hours and this is followed by a core melt activity release that extends over a 1.3 hour period. Consideration of any significant delay in containment spray actuation requires that the AST model be assumed. The previous model from Regulatory Guide 1.4 assumes an instantaneous release of activity from the core and a delay in spray initiation would result in large increase in the calculated doses.

Since it is assumed that there is no release of activity from the core for the first ten minutes of the accident because of taking credit for LBB, a ten-minute delay in spray initiation would have essentially no impact on the doses. As the delay is extended, the impact on the doses increases. The estimated changes in dose are:

Table 4.1-1: Time Delay vs Dose Increase

Time Delay to Containment Spray Initiation	Increase in Dose	
	EAB	LPZ
20 minutes	<0.5%	<0.5%
30 minutes	<2%	<2%
40 minutes	<6%	<4%
45 minutes	<9%	<6%
50 minutes	<13%	<8%

The lower impact on the Low Population Zone (LPZ) dose is to be expected since that dose is calculated over a 30-day period while the Exclusion Area Boundary (EAB) dose is calculated over a 2-hour period early in the accident.

It is apparent that a delay in actuating containment sprays should be readily accommodated at most plants. With a 45-minute delay, the estimated increase in the dose at the EAB is less than 9% and the increase in the LPZ dose is less than 6%. For a plant not taking credit for LBB, the times above are decreased by ten minutes.

4.2 Risk Evaluation for Containment Spray Delay

The potential safety benefits of delaying or eliminating the automatic initiation of containment spray was studied for a number of different containment designs. When actuated, containment spray results in a significantly faster draw-down of the Refueling Water Storage Tank (RWST) water inventory that is also used for emergency core cooling. As a result, the transfer to emergency core cooling recirculation occurs much earlier than if spray were not operating. This has two impacts on risk:

1) The earlier transfer to recirculation increases the human error probability for manual actions for those plants that require some operator actions during the transfer to recirculation, and
2) For smaller loss of coolant accidents, the transfer to emergency core cooling recirculation occurs before RCS cooldown and depressurization to Shutdown Cooling initiation can be implemented.

The potential safety benefits of delaying or eliminating containment spray automatic initiation that can be readily quantified by PRA are:

a) Changes in Human Error Probabilities (HEP) due to longer times available for transfer to recirculation and,
b) An alternate success path for small LOCA events.

The benefits were quantified by changing the small LOCA accident sequences and the transfer to recirculation HEPs in the "at power" PRA models and examining the impact of those changes on the Core Damage Frequency (CDF).

This assessment focuses on CDF because Large Early Release Frequency (LERF) is typically dominated by containment bypass events in which spray does not actuate and thus no change in LERF is expected. The other contributors to LERF are energetic events (e.g., hydrogen burns) and failure of containment isolation. These events are typically binned into the LERF classification regardless of containment spray operation.

4.2.1 Risk Impact for Various Containment Configurations

The different containment configurations for PWRs represent significantly different benefits as discussed below (also see Table 4.2-1).

Large Dry Containments (LDC) with Fan Coolers and High Spray Actuation Setpoint (on the order of 20 psig) – For these plant designs, containment spray is not actuated for small LOCA events. Also, containment spray is not needed for either short term or long term containment heat removal if minimum fan coolers are operating. For these plants, the benefit of changing the containment spray actuation is limited to increasing the time available to complete the transfer to ECCS recirculation. This plant configuration is the most prevalent of the PWRs shown in Table 4.2-1.

Large Dry Containments without Fan Coolers and High Spray Actuation Setpoint – For these plant designs, containment spray is not actuated prior to transfer to recirculation for small LOCA events. However, containment spray is needed for long term containment heat removal, but typically relies on the heat exchanger in the ECCS recirculation pathway to maintain a subcooled sump water temperature. For these plants, the benefit of changing the containment spray actuation is limited to increasing the time available to complete the transfer to ECCS recirculation.

Large Dry Containments with Fan Coolers and Low Spray Actuation Setpoint (on the order of a few psig) - For these plant designs, containment spray is actuated for small LOCA events prior to switchover to ECCS recirculation. Also, containment spray is not needed for either short term or long term containment heat removal if minimum fan coolers are operating. For these plants, the benefit of changing the containment spray actuation is both an alternate success path for the small LOCA using shutdown cooling and increasing the time available to complete the transfer to ECCS recirculation.

Subatmospheric Containments – These plants do not have safety grade fan coolers. For these plant designs, containment spray is actuated for small LOCA events. Containment spray is needed for long term containment heat removal. For these plants, transfer to ECCS recirculation is entirely automatic and therefore no change would be made to the human error probability for switchover to recirculation. The benefit of changing the containment spray actuation is both an alternate success

path for the small LOCA using shutdown cooling and increasing the time available to complete the transfer to ECCS recirculation.

Ice Condenser Containments – These plants do not have safety grade fan coolers. For these plant designs, containment spray is actuated for small LOCA events due to the low containment spray actuation setpoint. The ice beds limit the initial containment pressurization from the break mass and energy releases. Containment spray is needed for long term containment heat removal after all of the ice is melted. For these plants, the benefit of changing the containment spray actuation is both an alternate success path for the small LOCA using shutdown cooling and increasing the time available to complete the transfer to ECCS recirculation.

In general, W-NSSS and CE-NSSS plants rely on different approaches for long term removal of decay heat from the containment. For W-NSSS plants, long term heat removal following a loss of coolant accident is via a heat exchanger in the low pressure ECCS recirculation pathway. Low pressure recirculation is an integral part of ECCS recirculation as it also serves as a booster pump when high pressure recirculation is required. The containment spray recirculation path has no heat exchanger and its only purpose is to spray containment with subcooled containment sump water, where the subcooling is achieved by the heat removal in the low pressure recirculation pathway.

For the CE-NSSS plants, the heat exchanger for long term core heat removal following a loss of coolant accident where emergency core cooling recirculation is required is part of the containment spray recirculation path. In the CE-NSSS design, the low pressure pumps are not used for recirculation since the high head pumps can take suction directly from the containment sump. Most CE-NSSS plants have safety grade fan coolers which are capable of removing decay heat from containment in the long term. Thus, containment spray recirculation is not required for long term heat removal. Also, some CE-NSSS plants can piggy-back the HPSI pumps off the discharge of the containment spray pumps and the shutdown cooling heat exchanger. These plants can cool the sump water without spraying containment. Thus, the containment spray recirculation path provides subcooled water to the containment sump for use in core cooling by the high pressure recirculation pathway.

Therefore, while containment spray recirculation is generally not important for the prevention of core damage in the W-NSSS designs, it is an integral part of long term heat removal for the CE-NSSS designs. While the CE-NSSS designs would also benefit from changing the containment spray actuation setpoint, containment spray recirculation is needed if ECCS recirculation is used for long term core decay heat removal.

Table 4.2-1: Safety Benefit Aspects of Eliminating or Delaying the Containment Sprays

Plant	Cont. Type	No. of loops	Late Peak Calc. Pressure (psig)[1]	Design Pressure (psig)	P_a (psig)	Cont. Net free Volume (10^6 ft^3)[6]	Number of Safety Grade FCs	Cont. Spray Setpoint (psig)[5]	Cont. Mean Failure Pressure (psig)[4]	Cont. Lower Bound Failure Pressure (psig)[4]	Safety Benefit of TBS Break[2]	Cont. Analysis Benefit[3]	Notes[7]
1	Ice Condenser	4	11.50	12	12	1.20	0 of 0	2.5	36	36	Yes	Yes	t_F=6980.2s, ice benefit
2	Large Dry	4	41.84	50	42.8	2.758	2 of 4	20.0	98	–	No	Yes	t_F=460.6s
3	Large Dry	4	37.71	50	42.8	2.758	2 of 4	20.0	98	–	No	Yes	t_F=399.0s
4	Ice Condenser	4	13.21	15	14.8	1.20	0 of 0	2.5	76	55	No	Yes	t_F=6800s, ice benefit
5	Ice Condenser	4	13.30	15	14.68	1.20	0 of 0	2.5	84	55	Yes	Yes	t_F=7600s, ice benefit
6	Large Dry	4	~34.43	52	37.0	2.75	4 of 8	25.0 (SAL)	127	102	Yes	Yes	t_F=619.0s
7	Large Dry	4	42.00	47	42.4	2.61	3 of 5	22.0	111	101	No	Yes	t_F=1118.0 (uprate, ILRT=42.42)
8	Large Dry	4	45.82	47	52.0	2.61	3 of 5	24.0	126	–	Yes	Yes	t_F=1199.0s (uprate)
9	Large Dry	4	49.6	52	49.6	2.794	0 of 0	19.8 (SAL)	166	120	Yes	Yes	t_F=5000s
10	Large Dry converted from Subatmospheric	4	38.4 (see note)	45	38.57	2.26	0 of 0	8.0	117.7	97.2	No		t_F=18s
11	Large Dry	4	39.73	47		2.55	2 of 5	22.0	120	–	No	Yes	t_F=699s
12	Large Dry	4	37.82	47		2.62	3 of 5	25.0	109	90	No	Yes	t_F=446s
13	Large Dry	4	41.12	47		2.62	3 of 5	25.0	109	90	No	Yes	t_F=712.8s
14	Large Dry	4	47.3	60	48	2.50	2 of 4	27.0	128	111.6	No	Yes	t_F=130s
15	Large Dry	4	42.7	60	48.1	2.50	2 of 4	27.0	135	116.9	No	Yes	t_F=Late
16	Large Dry	4	45.9	50	48.3	3.063	0 of 0	18.2	136	103	No	Yes	t_F=123s
17	Large Dry	4	36.3	56.5	41.2	3.32	2 of 6	12.0 (SAL)	140	–	No	Yes	t_F=54s
18	Ice Condenser	4	11.13	12		1.20	0 of 0	2.5	69	37	Yes	Yes	t_F=5832s, Ice Benefit
19	Ice Condenser	4	10.9	13.5		1.20	0 of 0	–	–	–	Yes	Yes	t_F=6664.6s, Ice Benefit
20	Large Dry	3	43.8	54	48	2.00	1 of 4	30.0 (SAL)	102	92	No	Yes	t_F=264s
21	Large Dry	3	37.5	57	45.1	1.84	2 of 4	12.05	142	–	No	Yes	t_F=1000s
22	Large Dry	3	40.5	42	40.5	2.01	2 of	25.0	130	83	Yes	Yes	t_F=850 8s
23	Large Dry	3	41.8	45	44	2.266	2 of 4	5.0	168	90	Yes	Yes	t_F=17.5s
24	Subatmospheric	3	43.3	45	43.3	1.75	0 of 0	11.0	127	85	No	No	t_F=15.7s, MAAP Analysis
25	Subatmospheric	3	44.9	45	44.9	1.75	0 of 0	11.0	127	85	No	No	t_F=18.2s, MAAP Analysis
26	Large Dry	3	49.24	55		1.55	1 of 3	–	146	100	No	Yes	t_F=1059.5s
27	Subatmospheric	3	44.5 (see note)	45	44.5	1.70	0 of 0	10.3	120	83.4	No	No	t_F=18s
28	Subatmospheric	3	44.1 (see note)	45	44.1	1.80	0 of 0	13.75	120	83.3	No	No	t_F=19s
29	Large Dry	2	40.0	46		1.32	2 of 4	22.5	150	–	Yes	Yes	t_F=Late
30	Large Dry	2	40.0	46		1.32	2 of 4	22.5	150	–	Yes	Yes	t_F=Late
31	Large Dry	2	53.33	60.0		1.00	2 of 4	33.5 (SAL)	129	108	No	Yes	t_F=1110s, Uprating

Table 4.2-1: Safety Benefit Aspects of Eliminating or Delaying the Containment Sprays

Plant	Cont. Type	No. of loops	Late Peak Calc. Pressure (psig)[1]	Design Pressure (psig)	P_a (psig)	Cont. Net free Volume (10^6 ft^3)[6]	Number of Safety Grade FCs	Cont. Spray Setpoint (psig)[5]	Cont. Mean Failure Pressure (psig)[4]	Cont. Lower Bound Failure Pressure (psig)[4]	Safety Benefit of TBS Break[2]	Cont. Analysis Benefit[3]	Notes[7]
													Analysis
32	Large Dry	2	57.97	60	60	0.97	2 of	30.0	163	–	Yes	Yes	t_p=544.6s
33	Large Dry	2	44 6	46	46	1.32	2 of 4	23.0	121	–	Yes	Yes	t_p=19.9s
34	Large Dry	2	57.55	59	58	1.778	1 of 4	8.6			Yes	Yes	t_p=148.6s
35	Large Dry	2	49.2	50	49.5	1.989	2 of 4	4.75			Yes	Yes	t_p=175s
36	Large Dry	2	58.05	60	60	1.06	0 of 0	5.0			Yes	Yes	t_p=339.3s
37	Large Dry	2	52.9	54	54.00	1.90	2 of 4	9.48	150	102	Yes	Yes	t_p=181.0s
38	Large Dry	2	51.8 (see note)	55	55	1.64	0	3.7			No	Yes	t_p=14s
39	Large Dry	2	51.41	60	52.0	2.62	0 of 0	8.9			No	Yes	t_p=253.6s
40	Large Dry	2	45.9	60	60 0	2.305	2 of 4	3.4			No	Yes	t_p=267.0s
41	Large Dry	2	39.6 (see note)	44	39.6	2.5	2 of 4	10			No	Yes	Calc. Press. assumed to be second peak
42	Large Dry	2	40.0 (see note)	44	41.8	2.5	2 of 4	5.4			No	Yes	Calc. Press. assumed to be second peak
43	Large Dry	2	35.2 (see note)	39.6 (allowed 44)	45-49	2.677	1 of 4	5.0			No	Yes	t_p=12.62s

1. If the peak pressure occurs during the blowdown (such as for the DEHL break), the peak pressure should not be reported here. It would not be affected by eliminating or delaying the containment sprays. This pressure should be reflective of the peak pressure once the containment sprays have been actuated, the second peak, such as for the DEPS break.
2. This is based upon engineering judgment.
    - Yes - eliminating or delaying the containment sprays would cause the calculated peak containment pressure to exceed the design pressure, however going to a TBS break or lower, the calculated peak containment pressure would be below the design pressure.
    - No - eliminating or delaying the containment sprays would not cause the calculated peak containment pressure to exceed the design pressure
3. The answer to this is yes: a reduction in break size from a DE break to a TBS break would show a reduction in the calculated peak containment pressure.
4. Data taken from "PRA Survey Results for Reactor Cavity"
5. First cut data taken from "GSI-191: Summary and Analysis of US Pressurized Water Reactor Industry Survey Responses and Responses to GL 97-04", any follow-up more specific data is in bold.
6. First cut data taken from "PRA Survey Results for Reactor Cavity," any follow-up more specific data is in bold.
7. t_p =time of peak pressure

4.2.2 Generic PRA Model

Since containment spray is not comprehensively treated in most PRAs, it is difficult to determine the real impact on risk of changing the containment spray actuation requirements on a plant specific basis. Therefore a generic model has been constructed for large, medium and small LOCAs that includes the appropriate modeling of containment spray.

To assist in developing a quantitative assessment of the LOCA contributions to core damage, the WOG PRA Database was used to develop a representative total LOCA CDF and LOCA contributions to the total CDF. The results for large and medium LOCAs are shown in Table 4.2-2. For small break LOCAs, the W-NSSS ice condenser plants and the CE-NSSS plants were considered separately as shown in Table 4.2-3. For the CE-NSSS plants, the mean and median are significantly different because the small LOCA contribution to the total CDF was either in the 30 to 40% range or in the 1 to 2% range. These are the only plant classes that consistently have spray initiation for small LOCA events; the remainder of the plants would not realize a benefit from a change in containment spray initiation for small LOCAs. From this compilation, large and medium break LOCAs typically contribute between 4 and 10% of the total CDF while small LOCAs account for 15 to 30% of the total.

Table 4.2-2: Contribution to Total CDF from LOCAs

Statistic	% of Total CDF	
	Large and Medium Break LOCA	
	Injection	Recirculation
Mean	4.1%	6.9%
Median	2.0%	2.1%
Max	27.0%	40.9%
Min	0.0%	0.1%

Table 4.2-3: Contribution to Total CDF from LOCAs

Statistic	% of Total CDF			
	Small Break LOCA - CE-NSSS		Small Break LOCA - Ice Condenser	
	Injection	Recirculation	Injection	Recirculation
Mean	3.1	12.8	0.1%	30.8%
Median	2.3	2.6	0.1%	31.0%
Max	5.2	35.7	0.1%	34.0%
Min	1.5	0.1	0.1%	27.3%

A review of the importance measures for the operator actions for switchover to ECCS recirculation was also performed to assist in the determination of the contribution of the failed operator action to the total CDF for LOCA events. From this assessment, 73% of the large and medium LOCA CDF can be attributed to the failure of the operator action to switchover to ECCS recirculation. Similarly, 56% of the small LOCA CDF can be attributed to the failure of the operator action to switchover to ECCS recirculation.

For the case of no containment spray, the RWST inventory would not be depleted by the containment spray pumps. This would result in a lengthening in the time at which ECCS recirculation would be implemented by the operators. Table 4.2-4 provides an estimate of the RWST depletion rate with and without Containment Sprays (CS) for the large, medium and small LOCA events. This was taken from the success criteria and mission time analyses for a Westinghouse NSSS plant.

Table 4.2-4: Times Available for Operator Actions

	Time to Initiate Switchover to ECCS Recirculation (Minutes)		Time to Complete Switchover to ECCS Recirculation (Minutes)	
	With CS	Without CS	With CS	Without CS
Large LOCA	30	50	15	20
Medium LOCA	60	200	20	50
Small LOCA	65	900	20	150

Using the increase in time at which the operator action is required and the additional time available to complete the operator action, new estimated HEPs for the operator actions to switchover to ECCS recirculation can be developed by using existing HEPs for these different times. The HEPs for the large and small LOCAs with containment spray are taken from the existing PRAs of WOG member licensees. The HEPs for the LOCAs without Containment Spray (CS) are shown in Table 4.2-5 and were developed as discussed below.

Table 4.2-5: Human Error Probabilities

	With CS	Without CS
Large LOCA	1.9E-02	1.45E-02
Medium LOCA	8.0E-03	2.25E-03
Small LOCA	4.5E-03	1.00E-03

4.2.3 Results of Generic Risk Quantification for Containment Spray Delay

The generic model was quantified using the values derived above and the LOCA Initiating Event Frequencies (IEFs) from NUREG-CR-5750, as shown in Table 4.2-6.

Table 4.2-6: Spray/No Spray Quantification

Event	IEF	HEP	% CCDP Due to Operator Failure	CDF	Delta CDF
Large LOCA with Spray	5.0E-06	1.90E-02	73	1.30E-07	3.08E-08
Large LOCA without Spray	5.0E-06	1.45E-02	73	9.93E-08	
Medium LOCA with Spray	4.0E-05	8.0E-03	73	4.38E-07	3.15E-07
Medium LOCA without Spray	4.0E-05	2.25E-03	73	1.23E-07	
Small LOCA with Spray	5.0E-04	4.5E-03	56	4.02E-06	3.13E-06
Small LOCA without Spray	5.0E-04	1.0E-03	56	8.93E-07	
Large LOCA plus Medium LOCA					3.46 E-07
Large LOCA plus Medium LOCA plus small LOCA					3.47E-06

For plants where containment spray is only actuated for large and medium break LOCAs, the overall change in Core Damage Frequency (CDF) for LOCAs would be 3.46E-07. Using an overall CDF of 4.0E-05, this represents a 0.86% decrease in the overall CDF. This is also applicable to the CE-NSSS plants that have a very low (e.g., 1 to 2%) small LOCA contribution to the total plant CDF because even a modest change in the small LOCA CDF would not significantly impact the overall CDF. For the remainder of the CE-NSSS plant and the W-NSSS ice condenser plants, where containment spray is actuated for small, medium and large break LOCAs, the overall change in CDF for LOCAs would be 3.47E-06. This would represent an 8.7% decrease in overall CDF.

If credit is also taken for the ability to go to normal RHR cooling for those small LOCA events / cutsets involving equipment failures at recirculation, the change in CDF is found to be 2.20E-07. This represents an overall 9.23% decrease in CDF. The credit was only taken for cutsets not involving operator action failures due to possible dependencies between the two operator actions. Only crediting one or the other is conservative.

It is important to point out that there are additional benefits from delaying the actuation of Containment Spray that were not quantified. These benefits include:

- More RWST inventory available to be injected into the Reactor Coolant System for cooling the core.
- Reduction in the potential for the transport of debris that can block the containment sump during recirculation.

- Higher available nominal pump suction head at the sump for other ECCS pumps without the additional draw from the Containment Spray pumps.

These unquantified potential benefits may be more widely available if plants can demonstrate that the revised design basis event from the proposed rule change can be mitigated without Containment Spray or with substantially less Containment Spray flow.

Appendix A

Large Break LOCA Redefinition Program
Analysis Report on Reference Cases below Transition Break Size

1. Introduction

1.1 BACKGROUND / PURPOSE

This report provides analysis results used to support the LBLOCA redefinition program as described in Reference 1. Reference 1 documents a meeting held between the NRC and Industry in which the NRC solicited the help of Industry to help quantify the safety benefits of a draft rulemaking which would change 10 CFR 50.46 with regard to how LBLOCA transients are considered in design basis space. Specifically, the draft rule would reduce the required largest break to be analyzed via current methods to somewhere in the range of the largest attached pipe to the hot and cold legs. This would then allow potential relaxations in emergency diesel start time and possible variations on containment spray delivery.

With the goals of the draft rule as a consideration, several cases were identified which could help quantify the impact of delaying EDG start time. At the current time, this will only be done for a Standard 412 plant, realizing that additional cases may be required. The run matrix agreed upon at this time is:

- Current limiting small break case(s) (typically a 3 and 4 inch equivalent diameter break size for the Std 412).
- A 2 and 6 inch equivalent diameter was also executed consistent with cases that are being investigated by the NRC staff. The 6 inch case has ECCS flow spilling to containment in faulted loop.
- Cold leg break at accumulator/SI connection, using actual flow area of pipe, with ECCS flow spilling to containment in faulted loop.
- Same, plus 20% in flow area
- Same, minus 20% in flow area
- Hot leg break at pressurizer surge line connection, using actual flow area of pipe

This run matrix has the following expected benefits:

1) Includes actual piping flow areas
2) Addresses NRC desire to look for "cliff effects" in vicinity of TBS
3) Demonstrates pressurizer surge line break

Since the surge line flow area is typically larger than breaks analyzed by NOTRUMP, WCOBRA/TRAC will be used for that case. The licensing of WCOBRA/TRAC for use in best-estimate plus uncertainties applications included critical flow model assessments for breaks as small as 11.8 inches in diameter. This size is comparable to that of a pressurizer surge line (11.2 inches for 14-inch Schedule 160, and 12.8 inches for 16-inch Schedule 160). Although the code tends to under predict the critical flow somewhat for these tests, it is considered adequate for investigating the thermal-hydraulic behavior of a pressurizer surge line break. The NOTRUMP models are based on the Appendix K version of the EM. The accumulator line cases utilized the N-loop version of the NOTRUMP EM since it was judged that all loop seals would clear with this large of a break.

As stated above, the cases herein are based on the Std 412 NSSS design. The analysis input assumptions are documented in Reference 2. Note that Reference 2 was provided to NRC Research for use in the development of the TRACE and RELAP models that are also being used in this program.

2.0 NOTRUMP Analysis – DBA SBLOCA and Accumulator Line Break

2.1 METHOD DISCUSSIONS

As previously discussed, the NOTRUMP evaluation model was used for both the SBLOCA and accumulator line break cases. The model assumes all Appendix K requirements, including:

- ANS 5.1-1971 Decay heat + 20% uncertainty
- Moody Break Flow Model for two-phase conditions
- Modified Zouledek Break Flow Model for sub-cooled liquid
- Murdoch-Baumann Break Flow Model for single-phase vapor
- Failure of a single train of ECCS
- Minimum Safeguards ECCS flow rate (See Reference 2).
- Break is at bottom of cold leg with all ECCS lines injecting i.e., faulted loop ECCS lines spill to RCS pressure for break sizes less than branch lines. For break sizes 6 inches, or greater than branch line size, ECCS spill is to atmospheric pressure. (Note: The NOTRUMP EM normally would assume spill to RCS pressure for a 6 inch break in the 412 NSSS. Out of convenience, since the 6 inch case used the same N-loop model as the accumulator line break, the ECCS flows assumed spill to containment pressure.)
- Loss of off-site power coincident with reactor trip
- Some of the newer Std 412 NSSS's have safety grade PORV's on the main steam system; however, these were not credited in this analysis.

For the accumulator line break, two additional cases were run with a +/- 20% factor on break flow area (same as varying C_d) to see if any cliff effects were/are present in the size range of the accumulator pipe. Because the fault is in the accumulator line, the mass and energy releases from NOTRUMP do not include that from the faulted accumulator line.

2.1.1 NOTRUMP SBLOCA Cases – 3 and 4 Inch Equivalent Diameter

The SBLOCA cases run assume both a 3 and 4 inch equivalent diameter break size since these are the typical limiting sizes for a Std 412 NSSS. It is not expected that either of these sizes will come close to challenging the 50.46 criteria, even when a 60 second EDG start/load time is assumed. This is because even with Appendix K assumptions, the Std 412 NSSS ECCS system typically does well in mitigating the design basis SBLOCA transient. The base cases assume a 40 second total ECCS delivery delay, which includes a 10 seconds for EDG start and load. The remainder is for ESF bus sequencing, charging, IHSI and RHR system valve alignment, pump start and flow transversal time. This overall delivery time increases to 90 seconds after the S signal when 60 seconds is allotted for EDG start/load.

Transient Discussion

Three Inch Equivalent Break Size

The response of the RCS to a 3 inch equivalent break size is provided in Figure 2.1.1-1 thru Figure 2.1.1-6. Figure 2.1.1-1 shows RCS pressure vs. time. This shows typical SBLOCA behavior where the RCS depressurizes in a rapid manner to saturation conditions at which flashing in the system and the corresponding vapor generation maintain a quasi-constant fluid volume within the RCS thus halting the depressurization. At this time the main steam system safety valves become an additional means of RCS energy removal which causes the RCS to come to a temperature equilibrium corresponding to Tsat of the lowest safety valve setpoint. During this time frame the RCS proceeds through a two-phase natural circulation period and then into a reflux cooling mode. After loop seal clearing (at approximately 500 seconds), depressurization commences and continues in a quasi-linear manner until ECCS make-up flow exceeds break flow. As stated in the analysis assumption operator induced cooldown/depressurization is not modeled here. If it were, the depressurization trend would continue. There is no appreciable effect from the ECCS delay with regard to RCS pressure response other than some minor feedback from core mixture level. That is, because the delayed ECCS case has a slightly higher amount of superheat during the middle phase of the transient, the equilibrium that exists between pressure and specific volume results in some minor impact on pressure.

Vessel mixture level is shown in Figure 2.1.1-2. In this case it can be seen that for this break size, the delay in ECCS delivery has some implications on core mixture level, albeit small. The top of the active fuel for this plant design is 22 feet. As seen in the figure, about 2.5 – 3 feet of the core uncovers. Minimum mixture level occurs at about 1,600 to 1,700 seconds. When comparing this time to the pressure history, it is seen that RCS pressure is still above the gas cover pressure in the accumulators. A slight recovery in mixture level with a subsequent drop is noted at around 1,150 and 1,300 seconds for the delayed delivery and base cases respectively. This is due to contribution of mass from the uphill side of the faulted loop SG when the hold-up mechanism from co-current flow breaks down. Thus there is a temporary mass contribution back to the vessel from this which is insufficient to turn the transient around. Shortly thereafter, RCS pressure has decreased to the point where the transient turns around completely on pumped ECCS flow without help from the accumulators. Therefore the delay in delivery would likely have more of an impact for this case as compared to larger break sizes that rely on the accumulators to turn the transient around. As can be seen, the additional delay on ECCS delivery impacts core mixture level by about 1 foot.

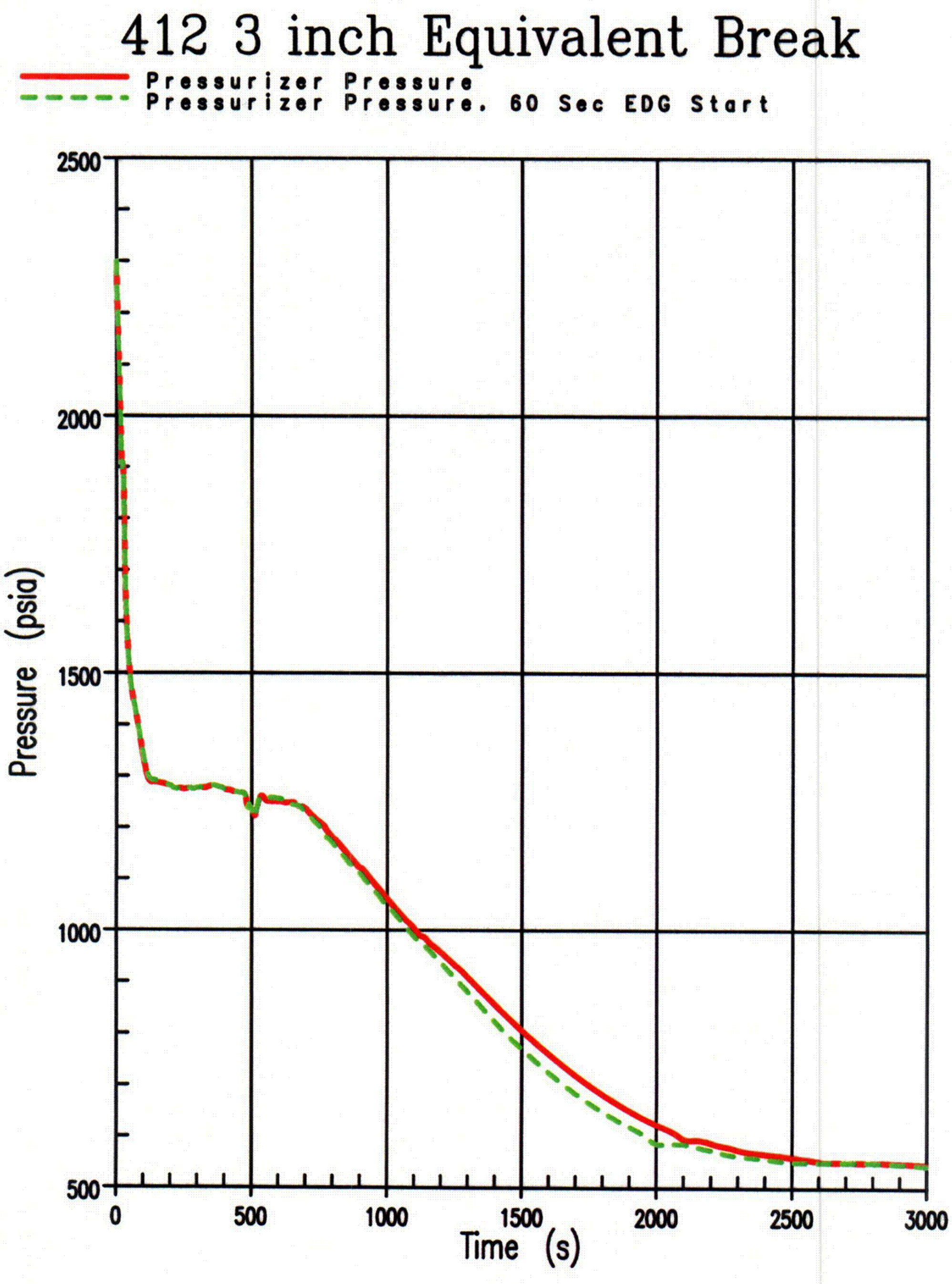
Core exit vapor temperature is shown in Figure 2.1.1-3. For the delayed delivery case, the vapor temperature departs from a saturated state at about 700 seconds indicating that core uncovery has occurred. This does not occur until 850 seconds for the base case. The slight dip in vapor temperature noted in the 1,100 to 1,300 second time frame is the result of the mixture level variation from SG drain-back discussed above. The maximum difference between the two cases is on the order of 60°F. Note that this is for the average rod channel vapor temperature. When peaking factors are considered along with boundary layer effects, the actual clad temperature will be higher. This is shown in Figure 2.1.1-6. From this figure,

it can be seen that the absolute difference in clad temperatures is on the order of 100°F. The 1,110 °F noted for the delayed ECCS case is well below the 10 CFR 50.46 criteria of 2,200°F and is typical of a Std 412 plant. The temperature is well below the area where oxidation starts to become significant and thus is not a factor in this analysis.

Break flow is shown in Figure 2.1.1-4. In this comparison, the break flow behavior is very typical. Loop seal clearing can be seen at about 500 seconds where break flow decreases significantly. At this time, break flow transitions from a low-quality, two-phase mixture to a saturated vapor and ultimately a super-heated vapor as the core uncovers. There are no notable differences between the two cases here, nor are there any expected.

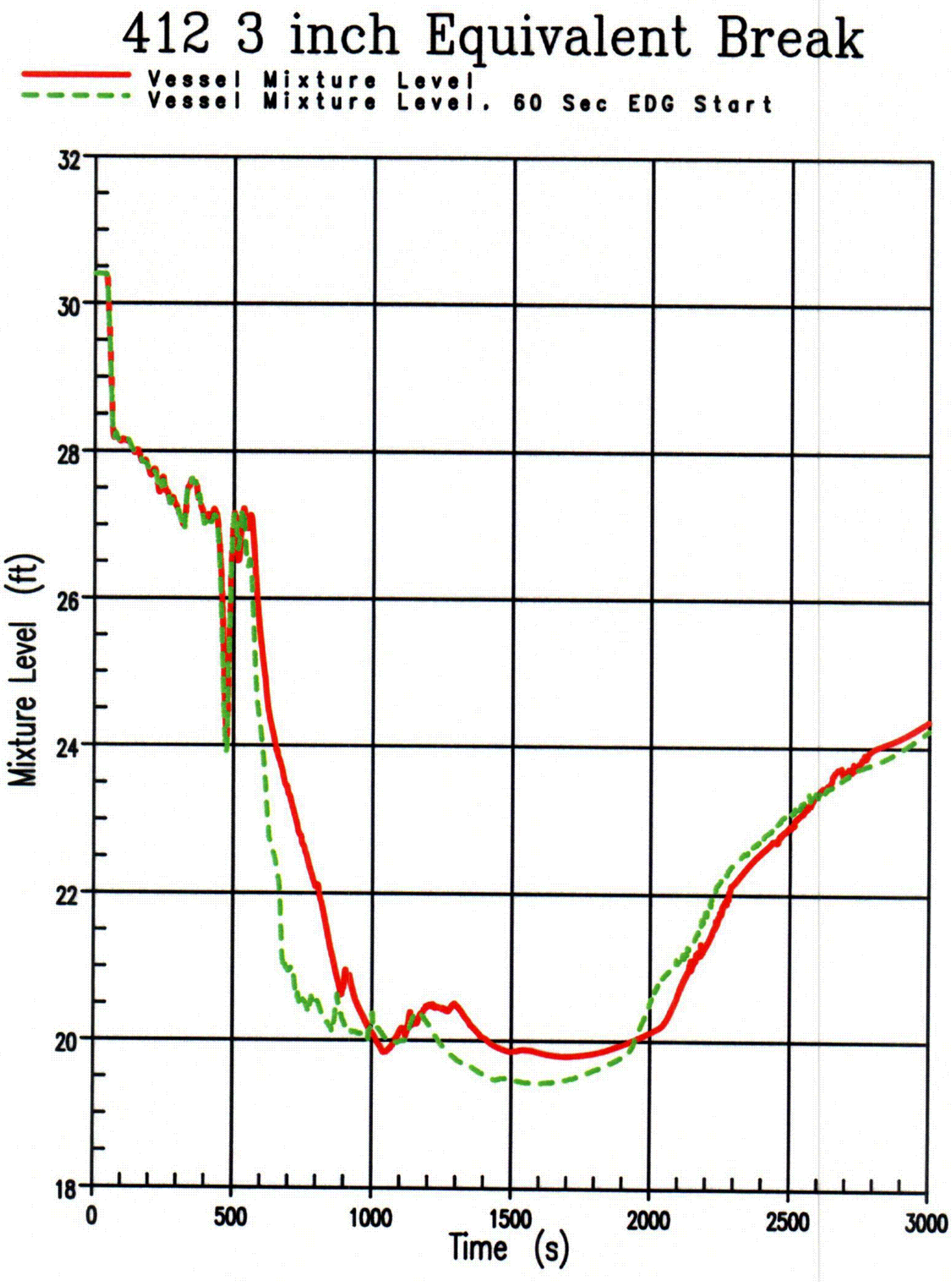
ECCS flow between the two cases is shown in Figure 2.1.1-5. The only notable differences are the delay in delivery and the slightly higher flow rate (later in the transient) for the delayed case brought on by reduced pressure during that phase.

Figure: 2.1.1-1



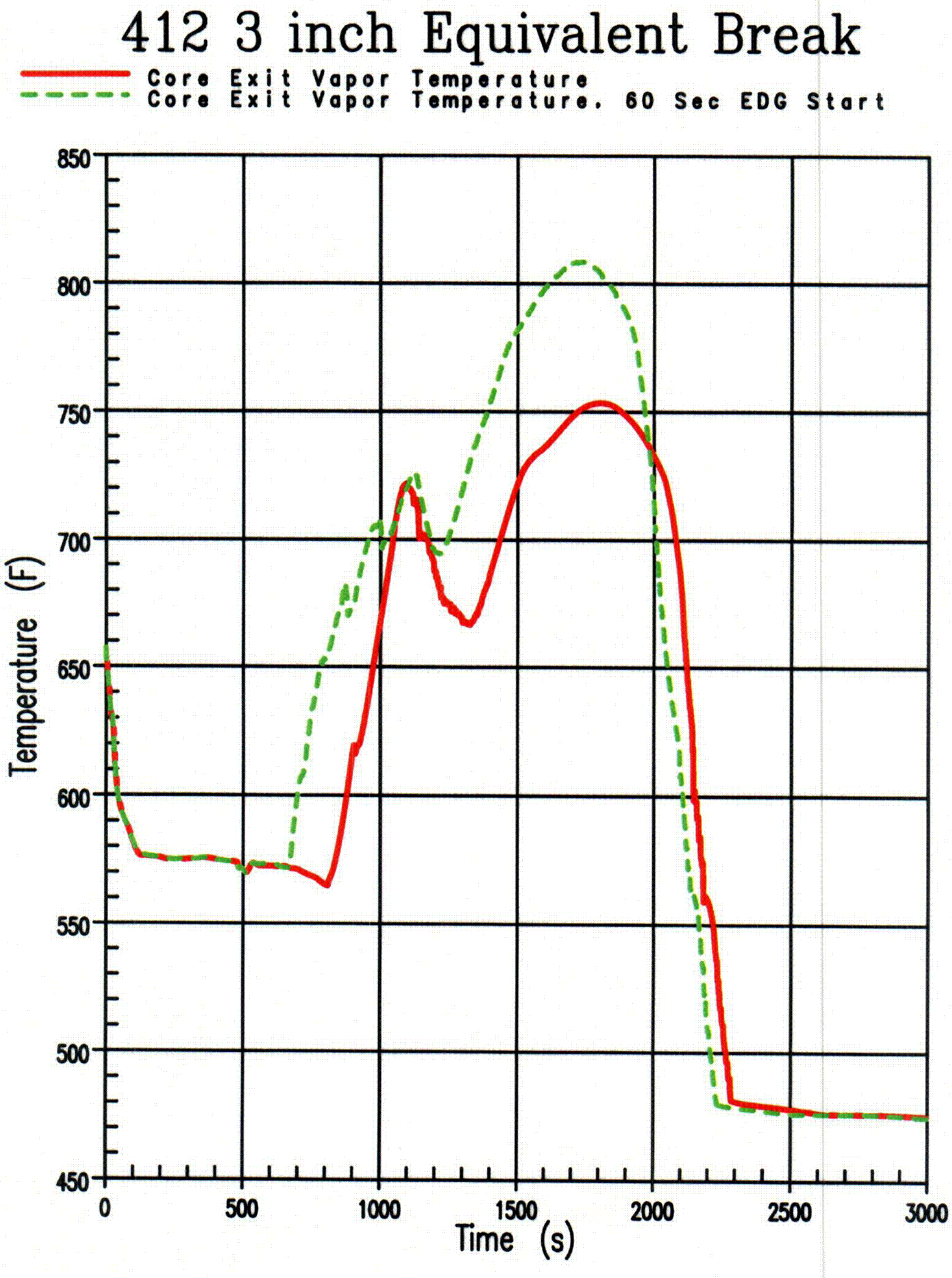
C01

Figure: 2.1.1-2



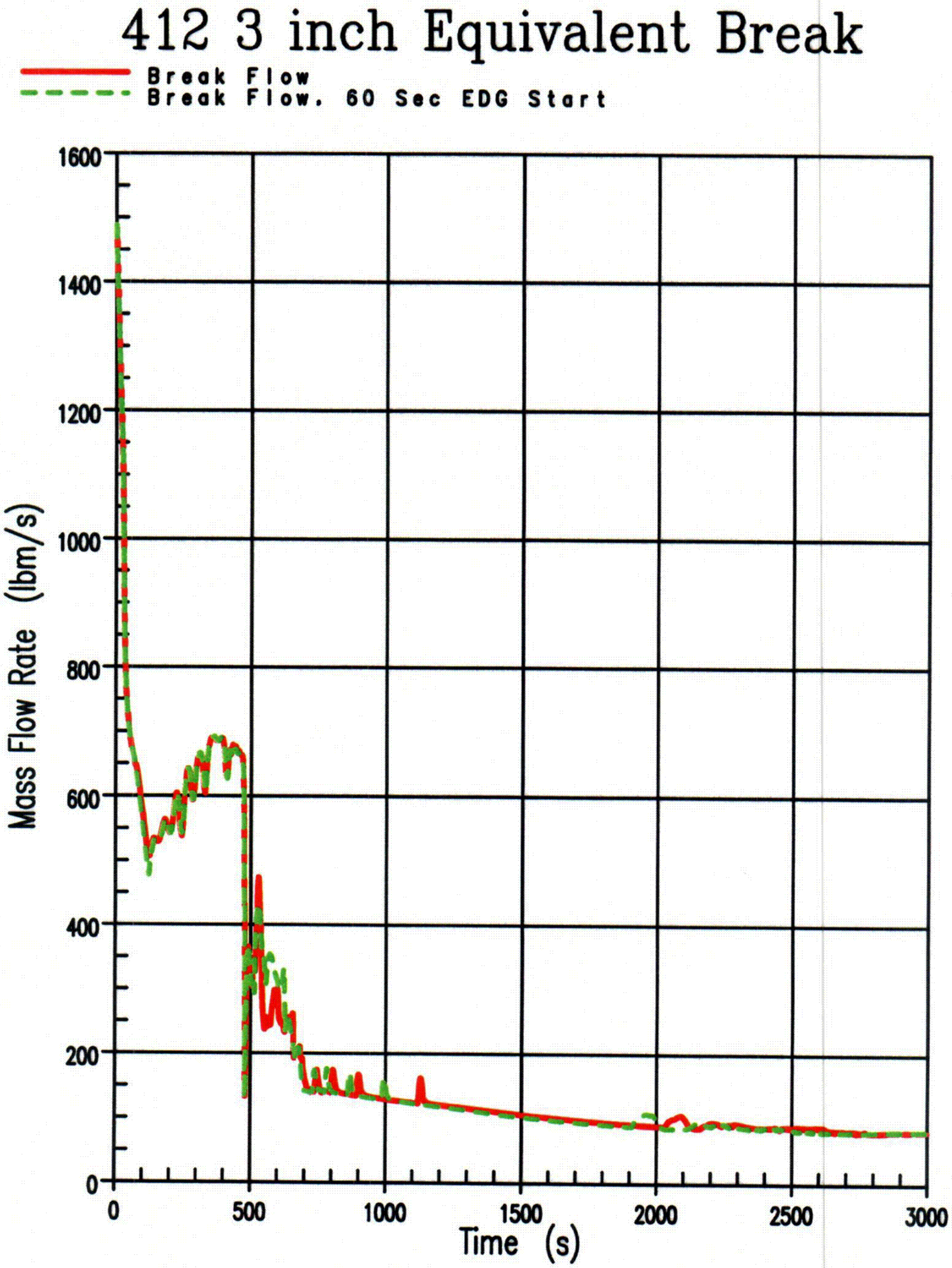
C02

Figure: 2.1.1-3



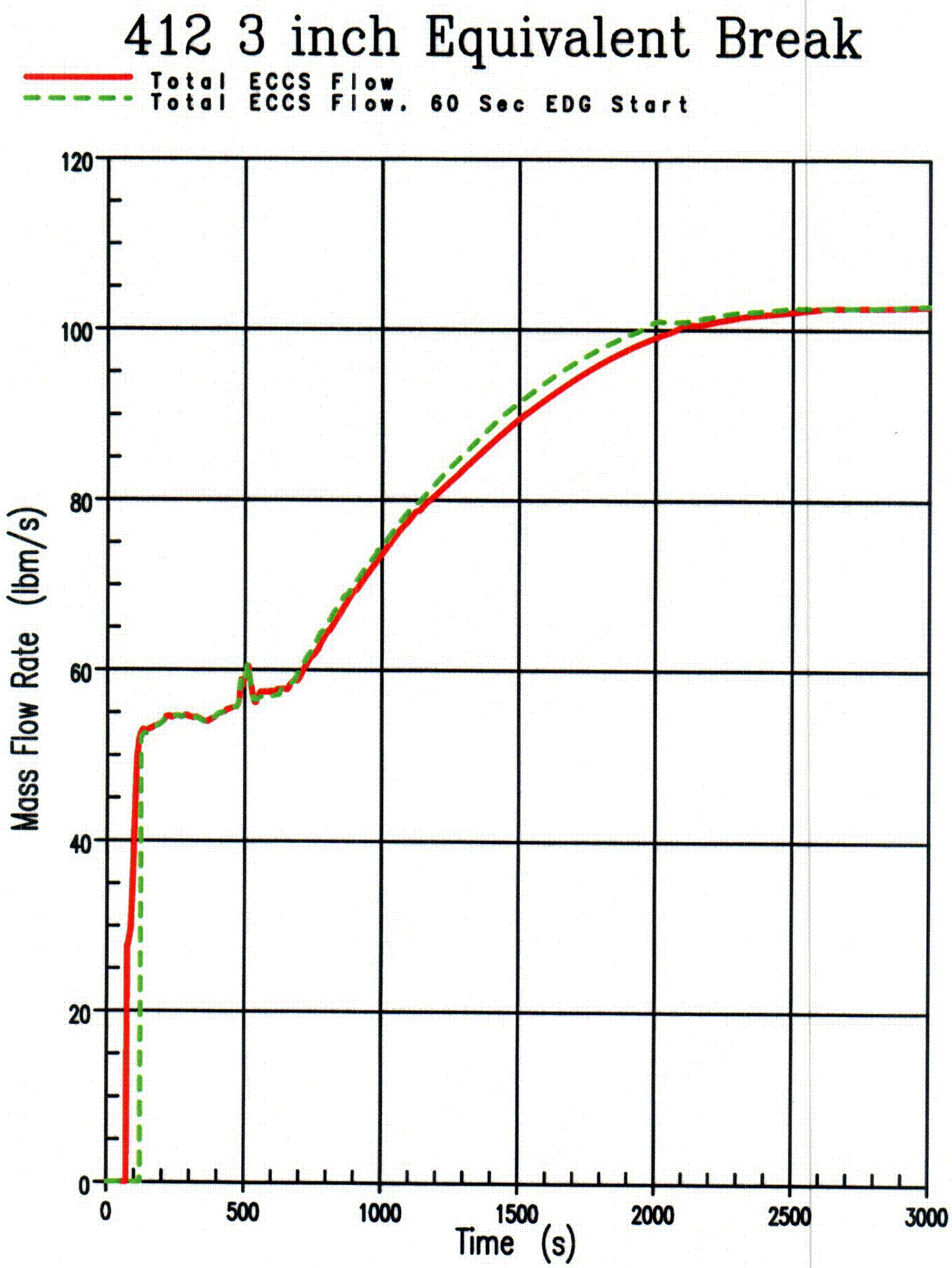
C03

Figure: 2.1.1-4



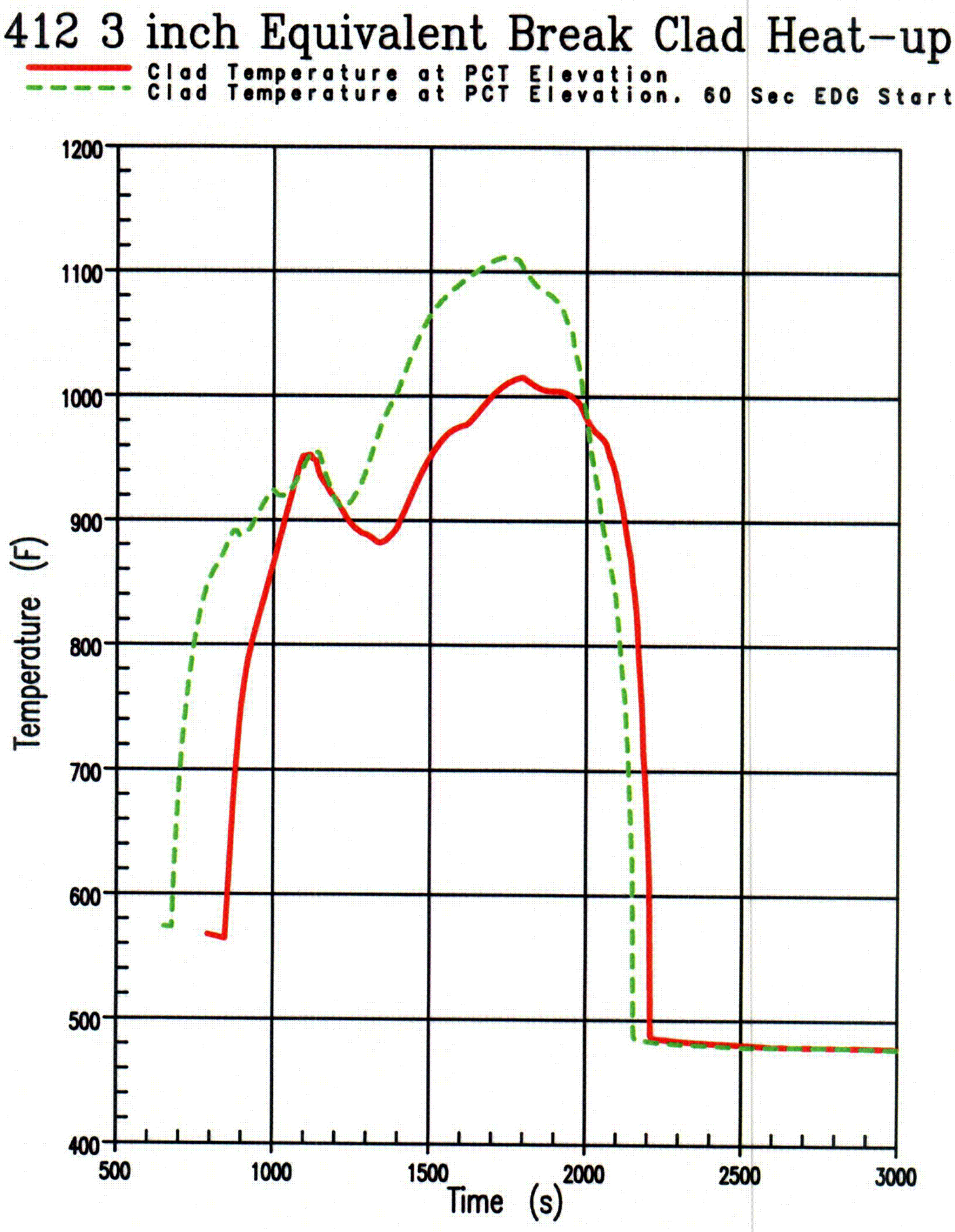
C04

Figure: 2.1.1-5



C05

Figure: 2.1.1-6

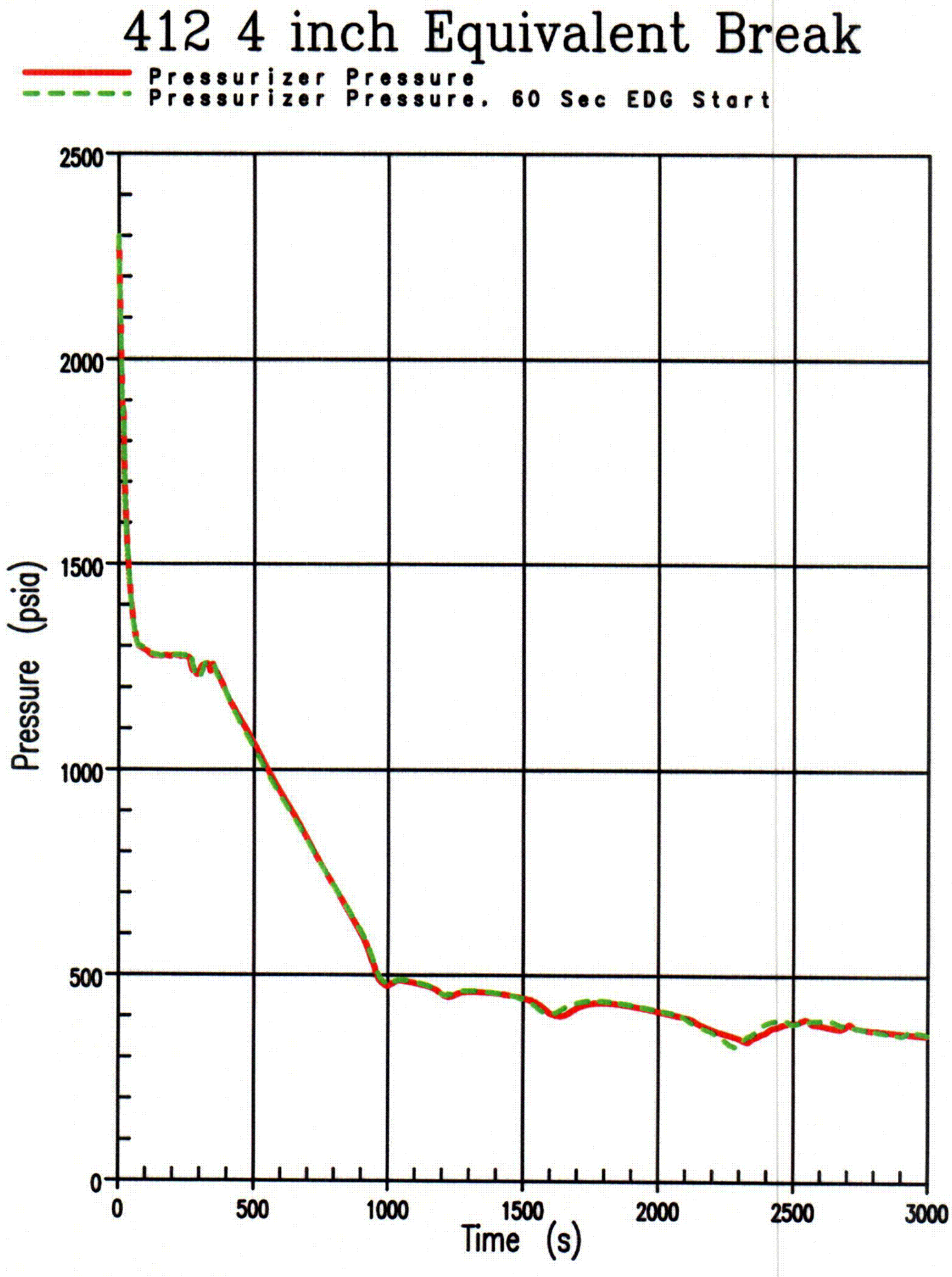


C06

Four Inch Equivalent Break Size

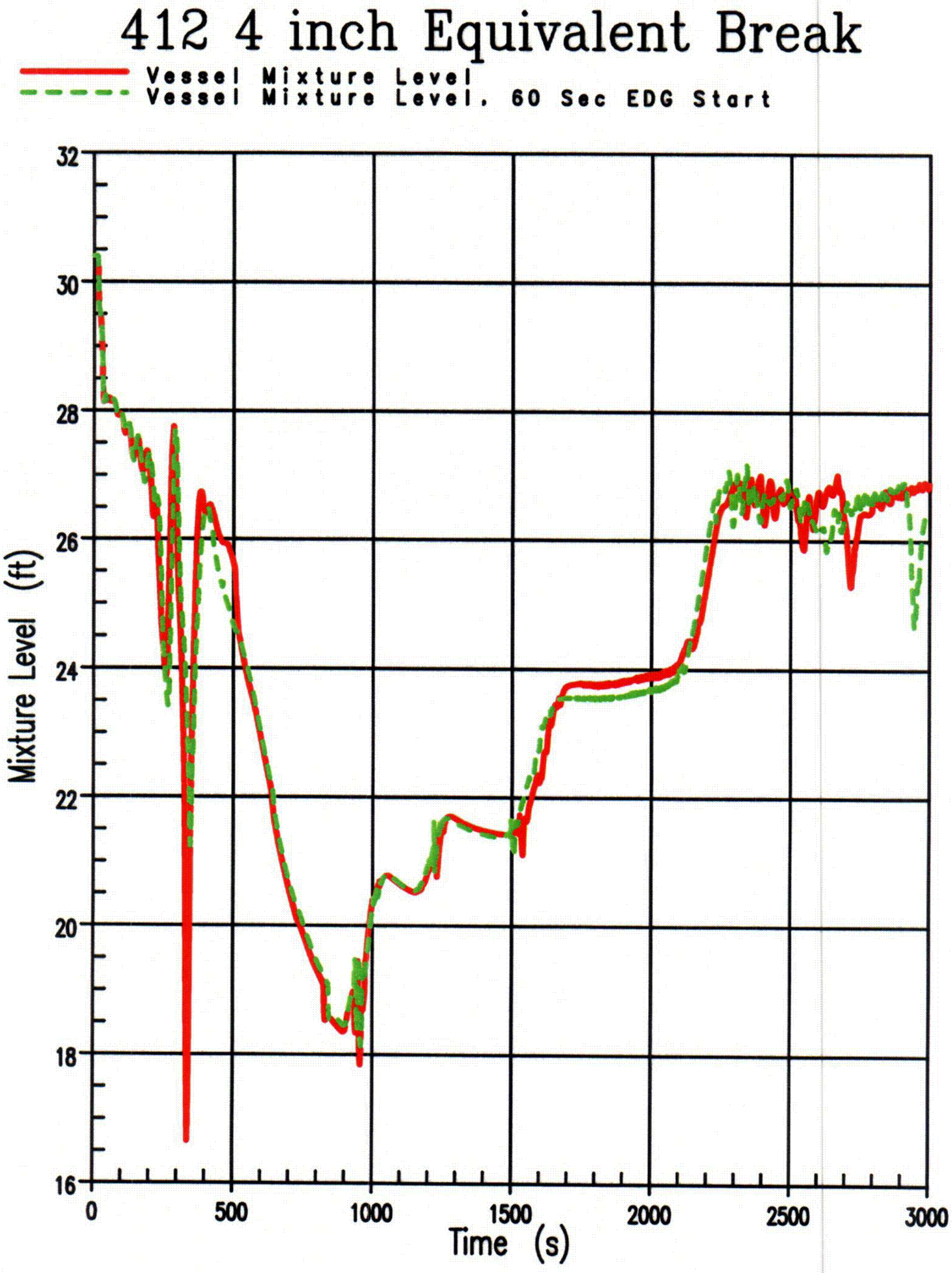
The response of the RCS to a 4 inch equivalent break size is provided in Figure 2.1.1-7 thru Figure 2.1.1-12. These are basically a repeat of the key variables shown for the three inch transient including pressure, mixture level, core exit vapor temperature, etc. In review of the transient, it is seen that there is no appreciable impact on ECCS delay for the 4 inch equivalent break size. This is mainly because as break size increases, more inventory is lost and the RCS depressurizes much more rapidly. As such, the accumulators become the more significant means to mitigate the transient. In this case, as shown in Figure 2.1.1-12, accumulator injection begins at about 900 seconds. Because the 4 inch break has a short pressure hang-up period, ECCS delivery very early in the transient is not significant. In fact, by the time the delayed case starts to deliver ECCS flow, the base case has only injected about 2,500 lbm. While this is not trivial, the high break flow and rapid progression to the accumulator injection point minimize this effect. As such, there is no appreciable effect by extending EDG start/load time by an additional 50 seconds for this break size in this plant type.

Figure: 2.1.1-7



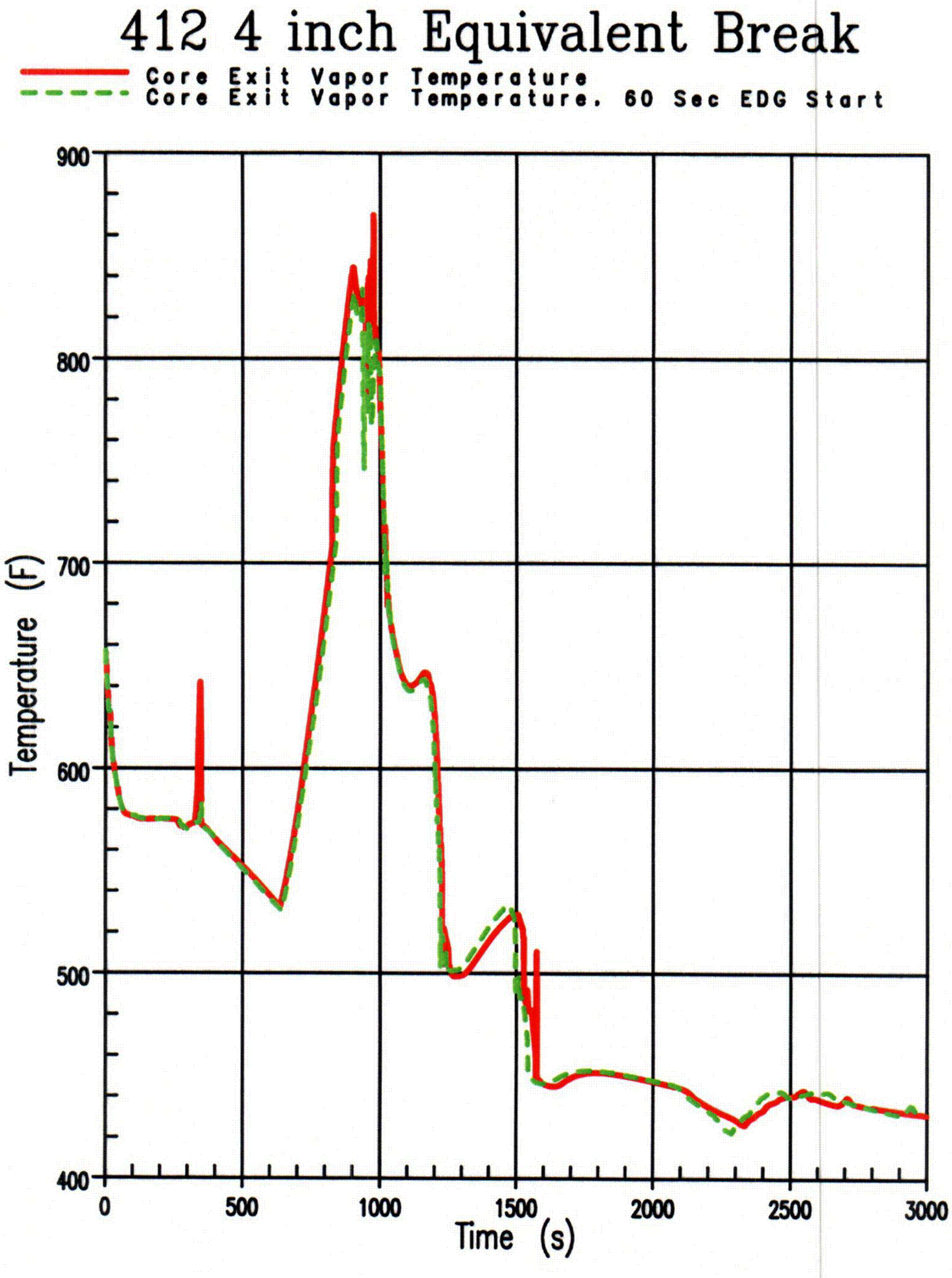
C07

Figure: 2.1.1-8



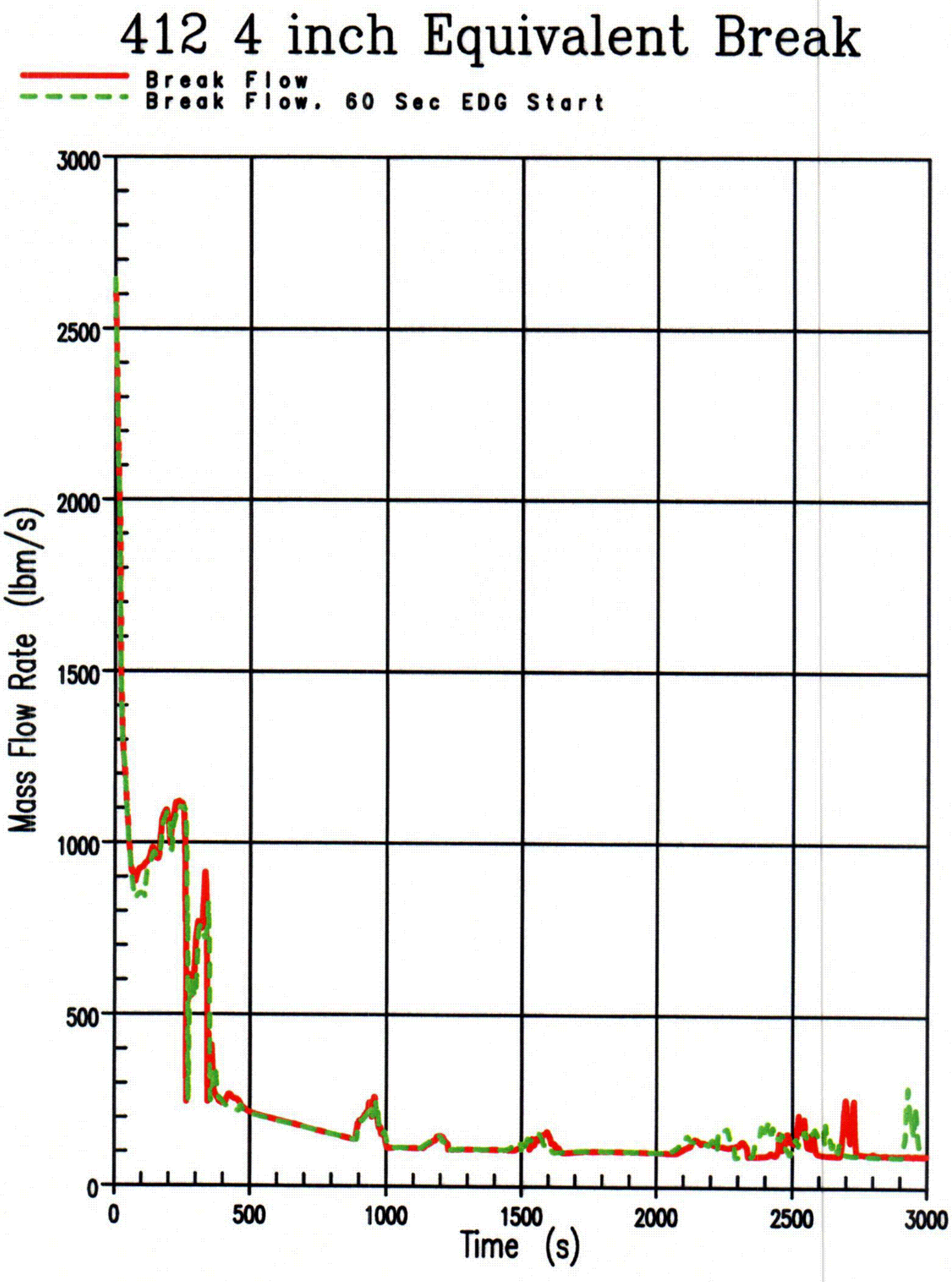
C08

Figure: 2.1.1-9



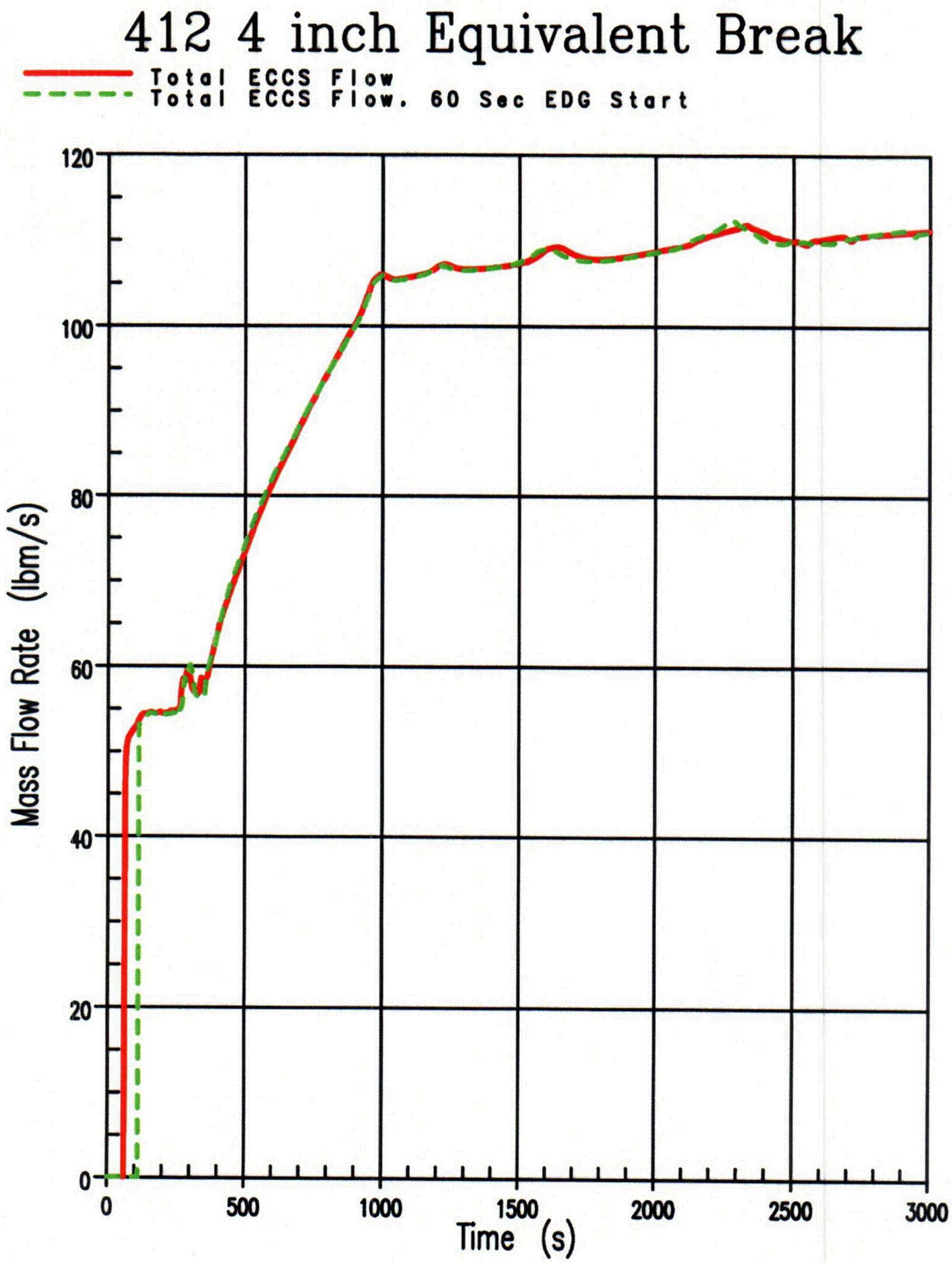
C09

Figure: 2.1.1-10



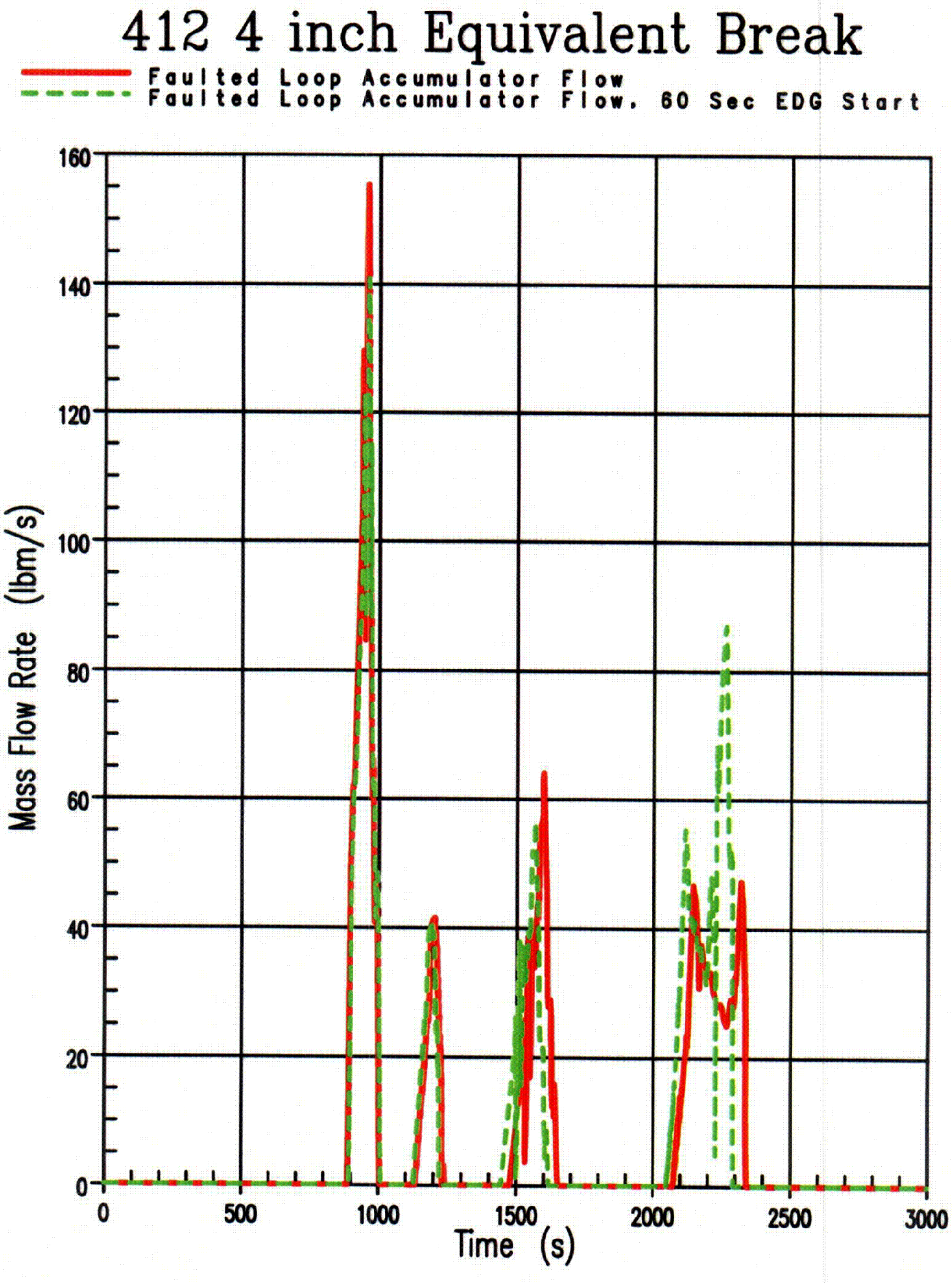
C10

Figure: 2.1.1-11



C11

Figure: 2.1.1-12



C12

2.1.2 NOTRUMP SBLOCA 2 and 6 Inch Equivalent Diameter Break Cases

In this study, two and six inch equivalent diameter break sizes were also investigated. No uncovery was noted for these cases as such no plots are provided. A brief discussion is provided below on the transient behavior for these two cases.

Two-Inch Case

In the two inch case, the integrated mass addition difference between the two cases is less than 1,500 lbm. However, the break flow for this case is low enough where the ECCS of the Std 412 design is not significantly challenged and therefore the deficit is not of significant impact.

Six-Inch Case

The six inch case is based on the N-loop model used for the accumulator line break. This was done for two reasons: (1) consistency with the NRC model and (2) the loop seals are expected to clear for this break size, as such there is no need to carry the artificial loop seal restriction. As stated in the assumptions, ECCS flow is assumed to spill to containment for this case. The results indicate that the six inch case is not significantly impacted since like the four inch case, the accumulators are dominant in turning the transient around. Again, no uncovery was noted for this case and the impact on ECCS delay is essentially un-noticeable.

2.1.3 NOTRUMP Accumulator Line Break Cases – 0.729 ft

For the accumulator line break cases, the NOTRUMP N-loop model was used, that is, all four loops were modeled. This was done since all loop seals are expected to clear for such a large break. In addition to the model assumptions listed above, the following applies for these cases:

- Accumulator line flow area for a Std 412 plant – 0.4176 ft^2 (single ended break, approx. 0.729 ft diameter)
- Additional cases of +/- 20% on flow area to capture any cliff effects
- Faulted loop accumulator and ECCS lines spill to containment
- COSI condensation model lower pressure limit extended from 550 psia down to 80 psia. This was done since: (a) for break sizes in this range, the RCS depressurizes well below the current limit quite rapidly, (b) the COSI model is almost purely driven by Reynolds number and is for the most part independent of pressure.

Transient Discussion

(Note that only the nominal break size is discussed as the variations on +/- 20% did not significantly impact the results).

The accumulator line break is illustrated in Figure 2.1.3-1 thru Figure 2.1.3-6. In looking at the behavior, this transient is much more indicative of a large break rather than a small one. However, depressurization is slow enough such that no instantaneous flow reversals occur in the core region. With positive flow maintained in the core during blowdown, stored energy is removed thus this significant aspect of an LBLOCA transient is not present in this case. With

the rapid depressurization, large amounts of accumulator water and pumped ECCS can be injected quickly thus minimizing overall system loss. It is noted that break size in this case is still small enough for the accumulators to handle until the ECCS can take over the demand. As such, some delay in ECCS delivery is tolerable. In summary this particular break size is quite favorable and no core uncovery is expected for these scenarios.

Figure 2.3.1-1 shows RCS pressure vs. time. Pressure in this case decreases in a monotonic fashion without the hang-up point that is representative of SBLOCA transients when saturation conditions are reached. The significant change in dP/dt that occurs just at approximately 200 seconds is due the injection of significant amounts of accumulator water. The significance here is that dP/dt is rapid enough to allow good depressurization of the RCS to where SBLOCA phenomena are absent while it's still slow enough to allow good blowdown cooling such that stored energy does not have much significance.

Core Mixture level is shown in Figure 2.3.1-2. From this figure it is seen that there is no core uncovery. In fact, there is no noticeable difference between the base and delayed delivery case. The oscillations present are a combination of a number of effects that are feeding back on the mixture level. These include downcomer and core void fraction variations, flooding in the SG tubes and liquid interaction with the break. Mixture level in this case is maintained well above the top of the core, which in this case is 22 feet.

Break flow and pumped ECCS flow are shown in Figure 2.3.1-3. Since all loop seals clear during blowdown, there is no distinct transition from mixture to vapor noticeable in the plot. As such, break quality continues to increase until the flow becomes a saturated vapor at about 150 seconds. The noticeable increases in break flow occurring just after 200 and at 500 seconds are due to accumulator injection with the break momentarily transitioning back to a low quality two-phase mixture. At about 950 seconds, pumped ECCS flow exceeds break flow. At this point the transient would more or less be considered over.

Applicability of NOTRUMP to Larger Breaks

Since NOTRUMP is a one dimensional code, there were some concerns about using NOTRUMP in larger breaks where two or three dimensional effects could come into play. The main areas of concern are two dimensional effects in the downcomer annulus around the cold legs where accumulator bypass and/or pumped ECCS entrainment could occur. In addition, the lack of a momentum flux model could also present limitations.

Accumulator and ECCS Bypass:

The potential for accumulator bypass can be seen in Figure 2.1.3-4. This figure shows downcomer mixture level and void fraction as a function of time and illustrates that the upper portion of the downcomer (above the loop nozzles, loop bottom elevation = 26.2 feet) is basically a saturated vapor through the majority of transient. While this condition presents the opportunity for accumulator and/or entrained ECCS bypass, as discussed below, this is not considered significant for this particular transient. Note that void fraction does have some minor impact on downcomer swell when two-phase conditions exist. (As an unrelated note, as shown in Figure 2.1.3-4 there is some evidence of downcomer boiling beginning

around 750 seconds, however, as pumped ECCS flow becomes significant, the downcomer returns to sub-cooled conditions.)

With regard to accumulator bypass, Figure 2.1.3-5 shows flow at the faulted loop cold leg nozzle and accumulator flow from one of the intact loops (loop 2). In this figure, as would be expected, it is seen that a significant flow reversal occurs through the faulted loop beginning around 40 seconds. This indicates the flow momentum is overcome by the sharp pressure gradient which could also influence injected accumulator flow. However, it is also shown that system pressure is too high during this time frame and the accumulators do not inject until 180 seconds. By this time a significant portion of the blowdown has occurred and most of the accumulator flow is directed into the downcomer. There are some additional flow spikes, but these are due to additional accumulator surges which drive up downcomer level where it spills into faulted cold leg. Thus accumulator bypass is not considered significant here.

Based on observed downcomer vapor azimuthal velocities, ECCS Bypass (entrained pumped ECCS carried via vapor flow through the downcomer annulus) does not appear significant. Figure 2.1.3-6 shows the vapor velocity at the faulted cold leg nozzle. For the vast majority of the transient, the velocity is below 20 ft/s which is considered to be below the threshold where a significant amount of the liquid phase would be swept away with the vapor, especially from the cold legs opposite the faulted loop side. This can be justified with the Upper Plenum Test Facility test data, Reference 3. In this document, ECCS entrainment effects through the downcomer are discussed. Figure 4.2-7 in this document shows the effect of steam flow through the upper portion of the downcomer and its impact on downcomer water level. In this figure, various intact loop steam flows are shown along with their impact on what is referred to as downcomer void height. That is, the effective impact to downcomer driving head. A value of 0 indicates no impact while a value greater indicates that some reduction in driving head is occurring due to ECCS entrainment. In Figure 4.2-7 it is shown for Test 25A, that with a loop steam flow of 50 kg/s, there is basically no ECCS entrainment. Test 25A was run at a pressure of 35 psia. When using the dimensions for the UPTF downcomer annulus, the calculated azimuthal velocity is 417 ft/s. When scaled to PWR conditions, this equates to a velocity of 220 ft/s. This is an order of magnitude higher than what was predicted in the NOTRUMP run. Thus ECCS entrainment in the accumulator line break is not of concern.

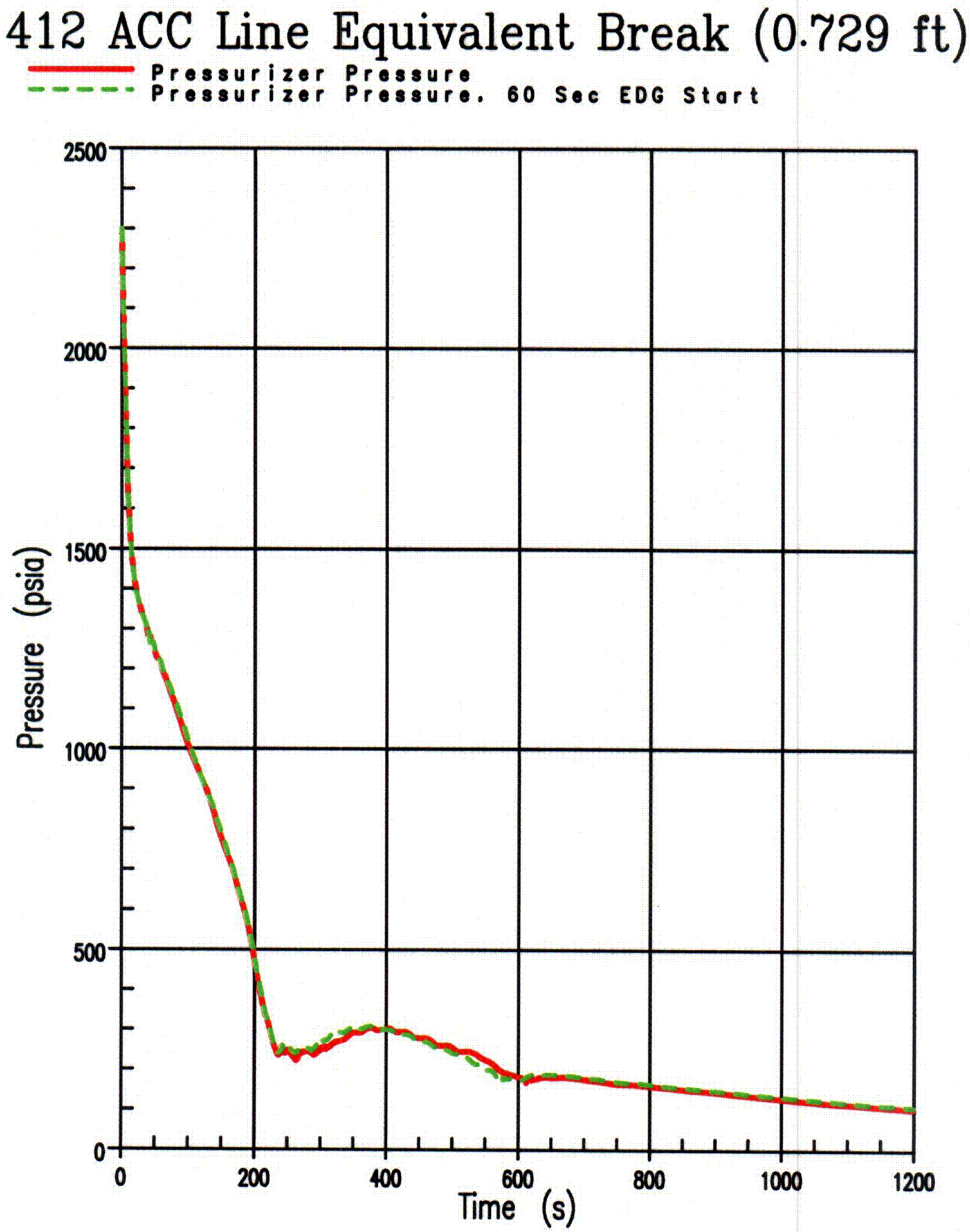
Momentum Flux:

In the modeling of AP-600/1000 there was a significant concern over the use of NOTRUMP since it does not have a comprehensive momentum flux model. This could conceivably have some impact on ADS line pressure drops due to flow acceleration effects. Specifically the ADS-4 flow paths which are critical to plant depressurization and inventory recovery. Thus it was considered necessary to quantify any abrupt area or density changes and its impact on flow acceleration.

For the accumulator line break scenario, this is not considered to be as significant of a concern. True, the accumulator line break is a branch line break and pressure drop effects due to momentum flux to the branch could be a factor. However, the main impact would be on break donor conditions. That is, if momentum flux was considered, among other things the upstream pressure of the break would be lower and thus break flow would be less for a

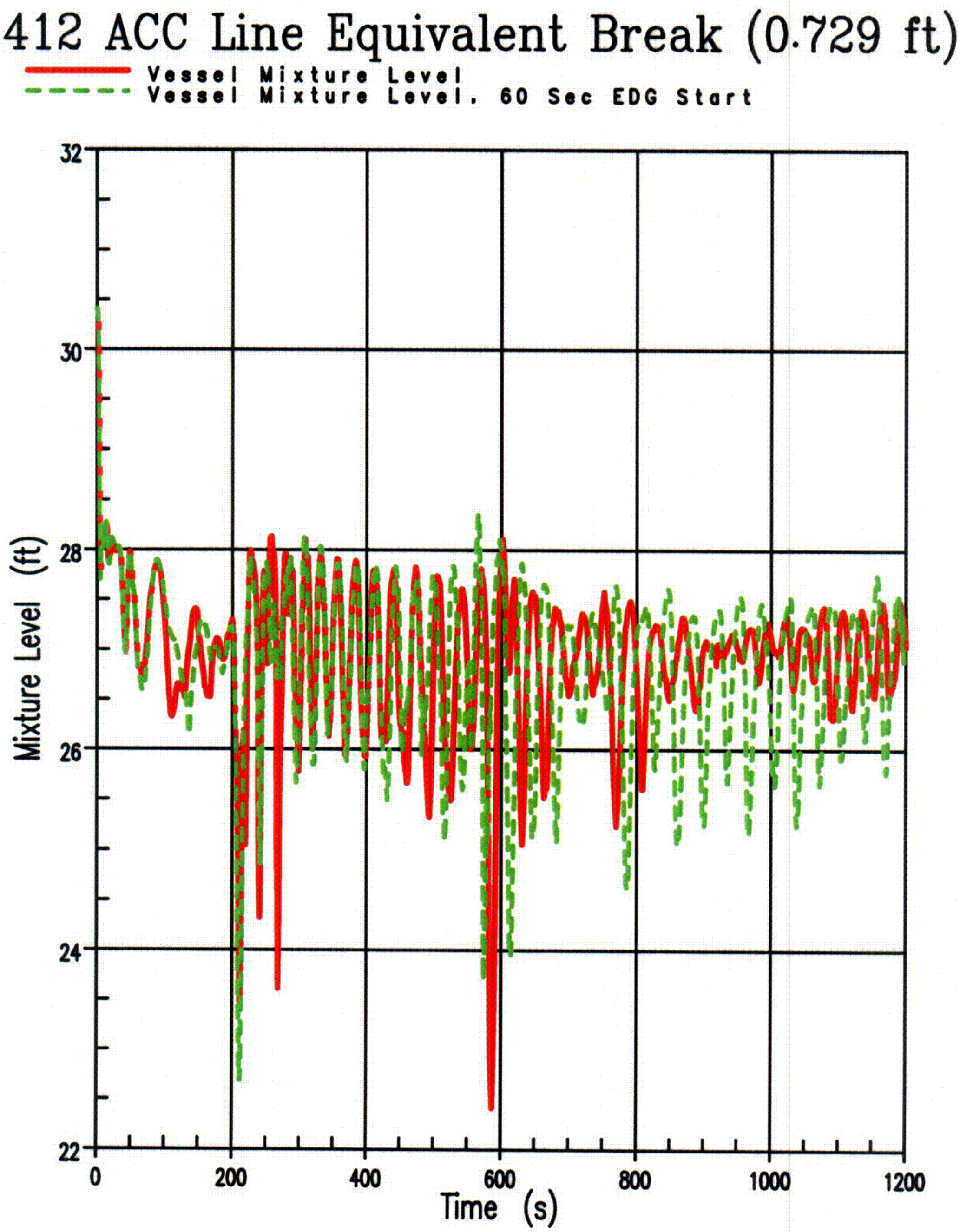
given break size. This would tend to reduce depressurization effects. In this case there are two key analysis modeling features which dominate this potential behavior. These are: (a) the break modeled directly at the cold leg bottom and (b) the use of the Moody break flow model. Since the break is modeled at the cold leg bottom, break flow is higher than it would be for a true branch line break if momentum flux and its effect on upstream pressure were considered. The break modeling at the bottom of the cold leg reduces vapor discharge and thus depressurization characteristics since the vapor must be pulled through the mixture phase to the break until the break eventually becomes uncovered. In addition, it is well known that the Moody model over-predicts break flow under low quality two-phase conditions. Thus, the manner in which this case is modeled, liquid mass loss is considered to be greater than it actually would be if these other effects were accounted for. Since acceptable results are obtained for this break size considering this modeling, no further detail in the model is required. Additionally, the effect of smaller breaks, are considered in the break spectrum.

Figure: 2.1.3-1



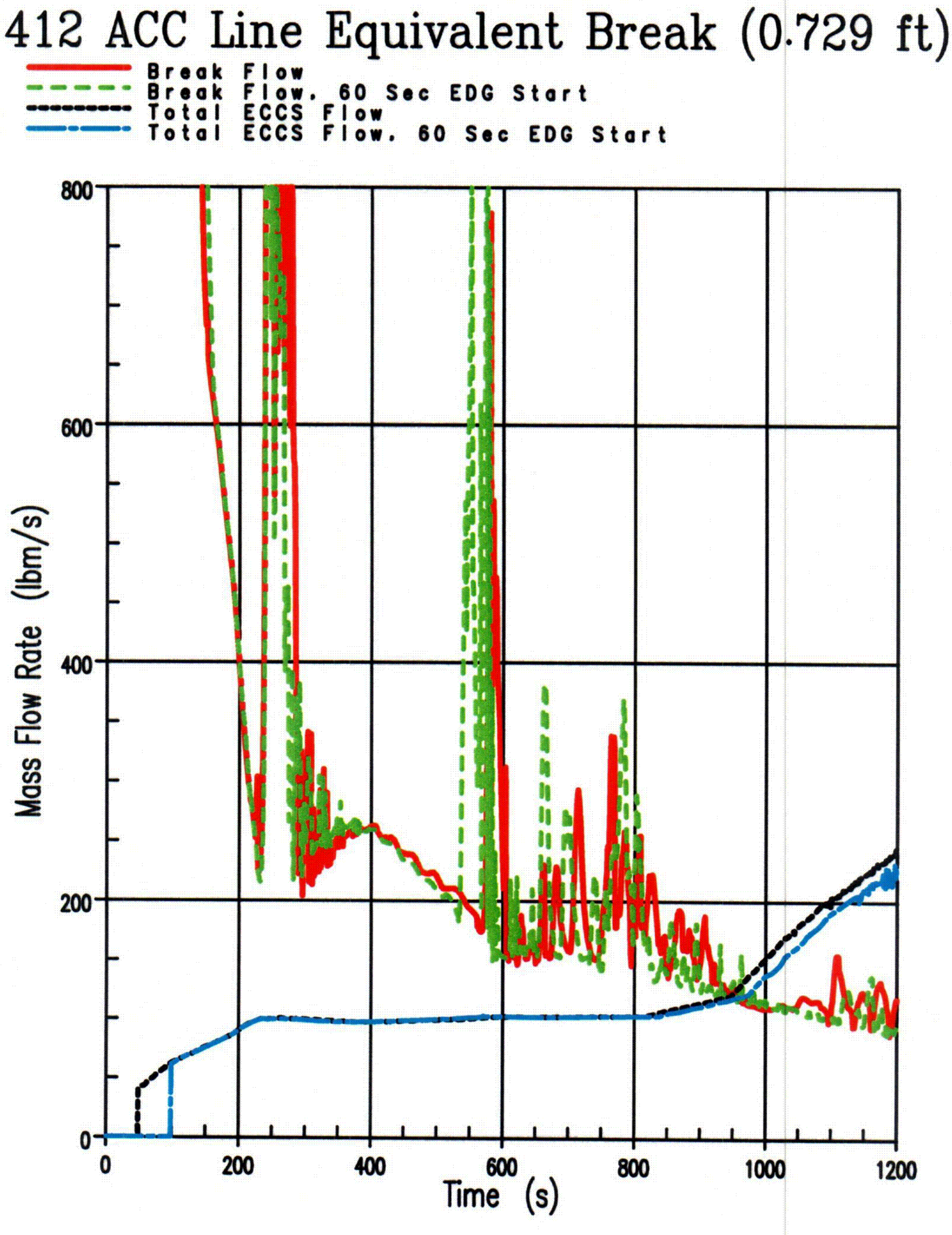
C13

Figure: 2.1.3-2



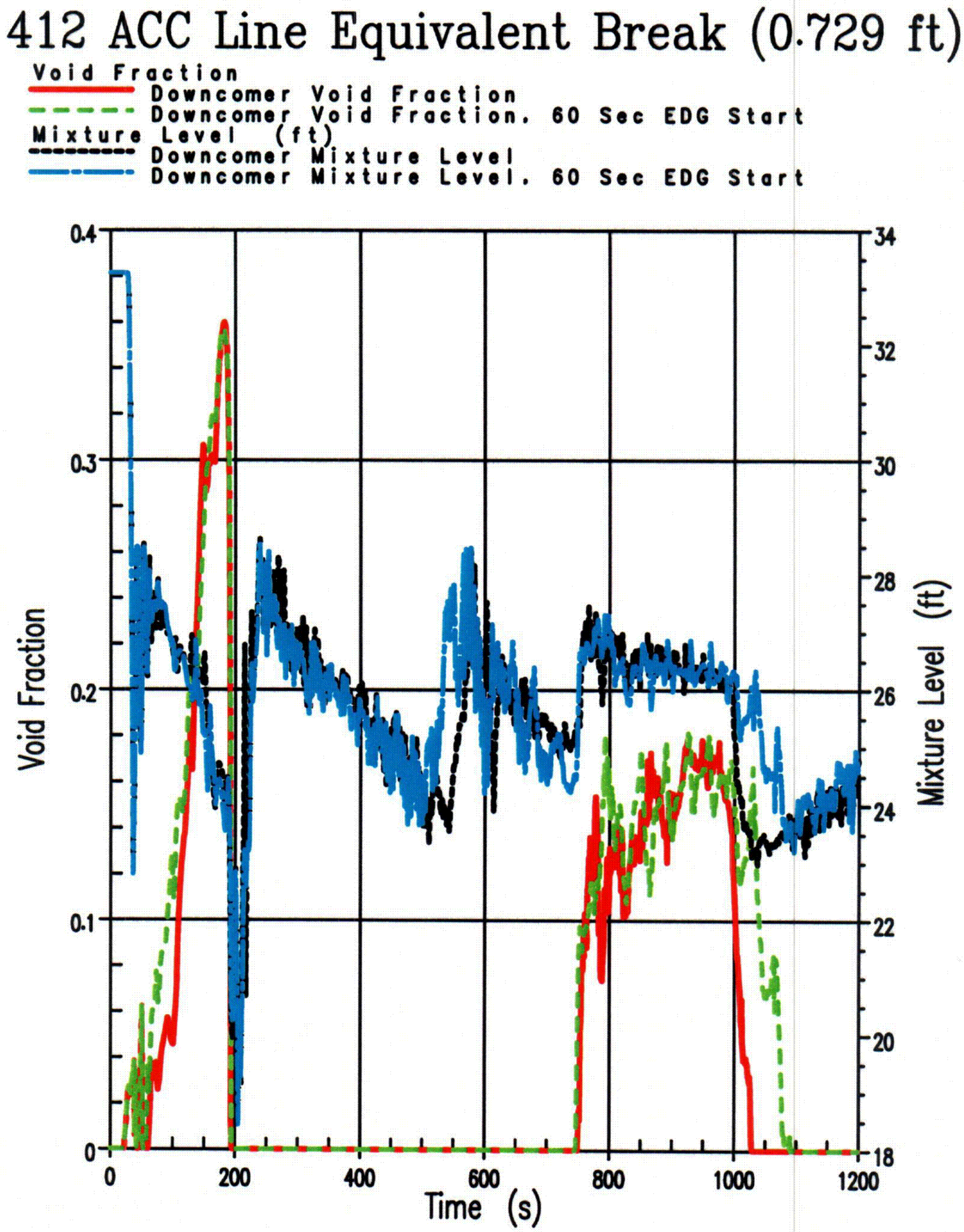
C14

Figure: 2.1.3-3



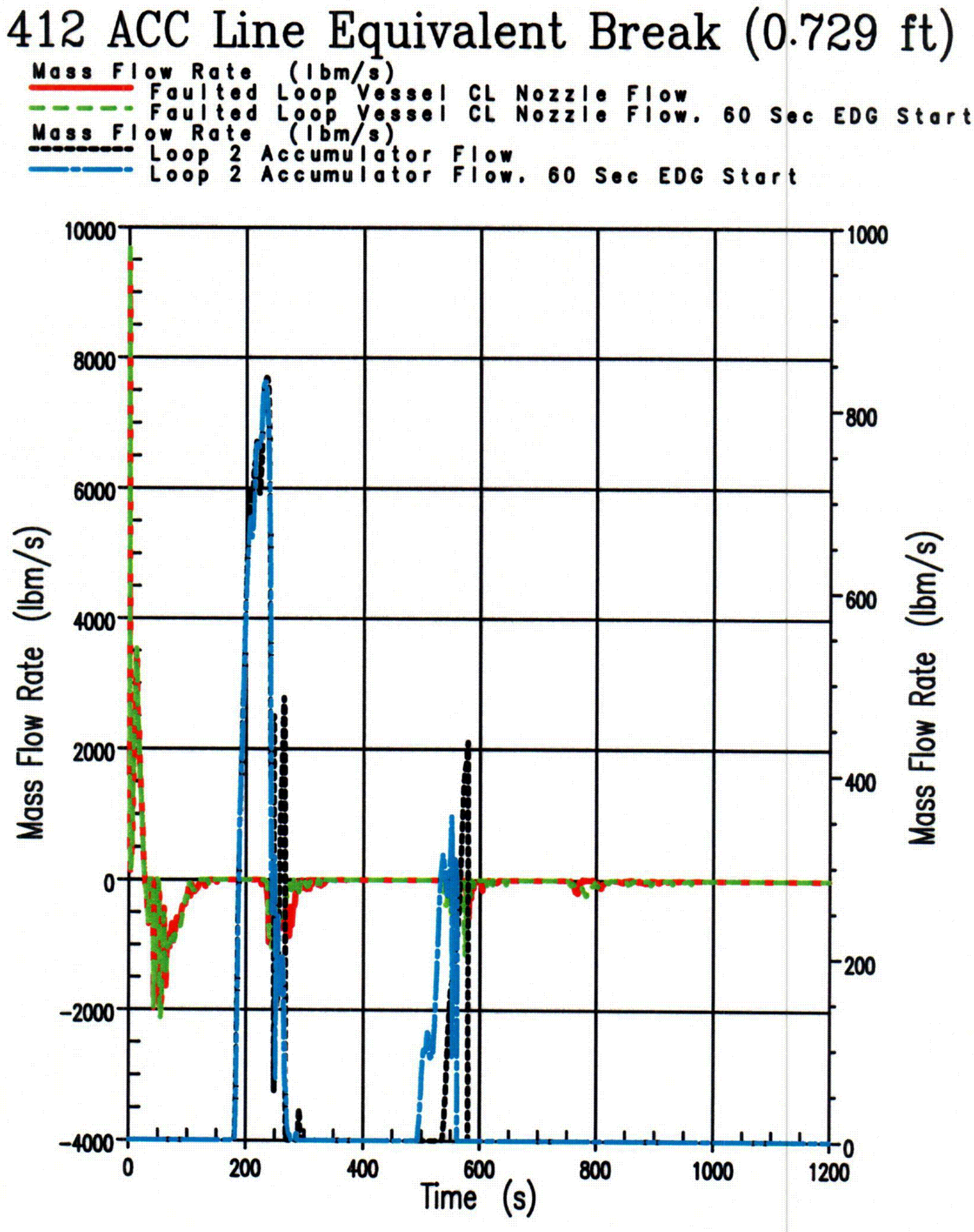
C15

Figure: 2.1.3-4



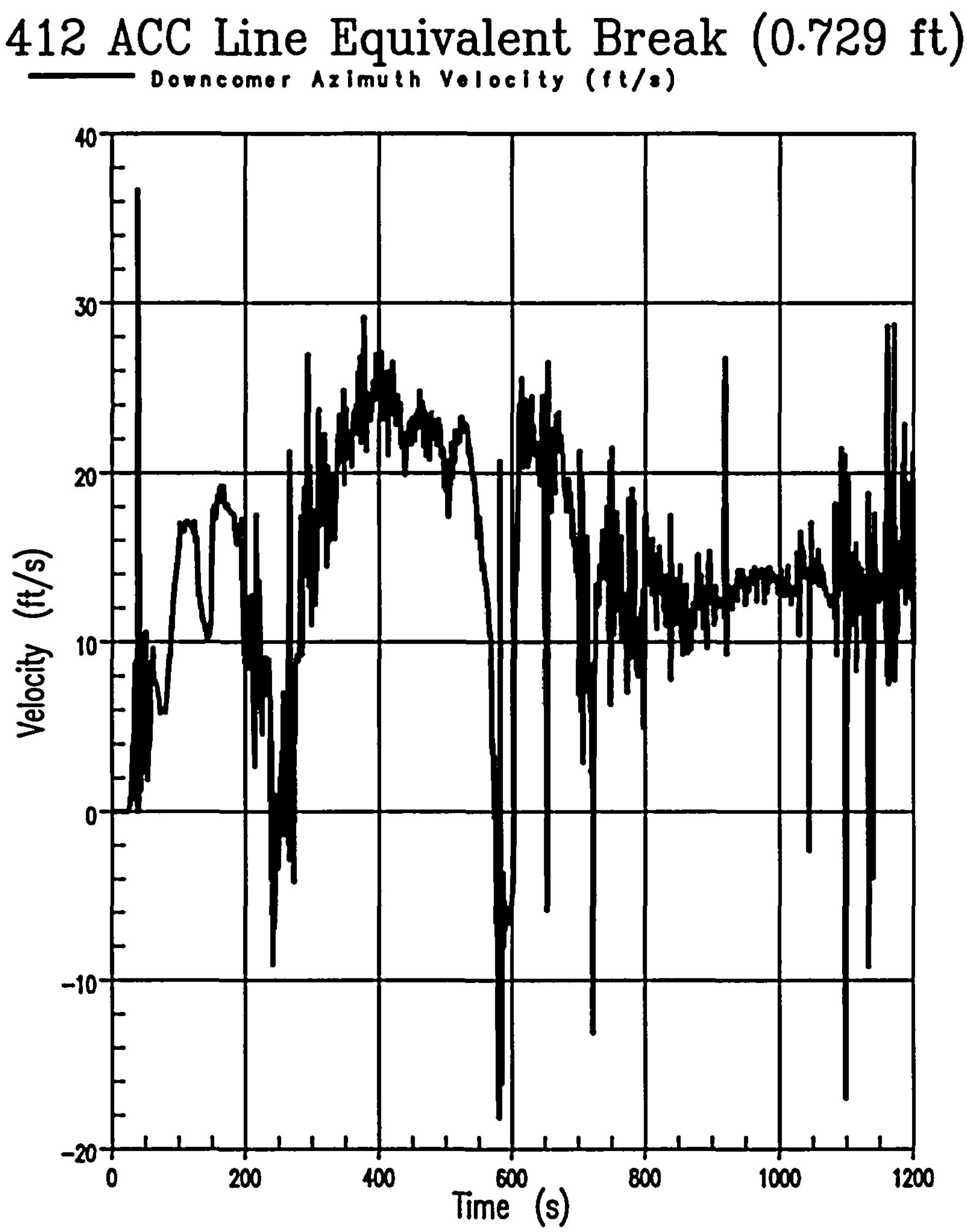
C16

Figure: 2.1.3-5



C17

Figure: 2.1.3-6


412 ACC Line Equivalent Break (0.729 ft)
Downcomer Azimuth Velocity (ft/s)
40
30
20
10
0
-10
-20
Velocity (ft/s)
0
200
400
600
800
1000
1200
Time (s)

3.0 WC/T Analysis – Surge Line Break

3.1 METHOD DISCUSSION

As previously discussed, the Reactor Coolant System (RCS) response to a pressurizer surge line break is to be evaluated as part of the LBLOCA Redefinition program; the surge line being the largest branch pipe connected to the RCS. The Emergency Diesel Generator (EDG) start time is to be varied to account for a 60-seconds delay and the effects of flow area variances are also to be assessed. The WCOBRA/TRAC evaluation model is used for this analysis. For consistency, a standard 412 Westinghouse NSSS design was agreed upon for all transient studies related to the LBLOCA Redefinition scope.

Once the base case is run ($C_d = 1.0$) with and without EDG start/load delay, two (2) additional cases with a flow area variance of ± 20 % ($C_d = 1.2$ and $C_d = 0.8$) are evaluated.

3.2 PRESSURIZER SURGE LINE BREAK INPUT

A Double Ended Guillotine Break (DEGB) is assumed to occur on the surge line pipe under Loss of Offsite Power (LOOP) conditions. Since the pipe is severed, the pressurizer is completely removed from the system. The break location along the surge line pipe is arbitrary in this study.

The following major assumptions are made for the pressurizer surge line break analysis:

- Failure of one (1) Emergency Core Cooling System (ECCS) train,
- Remaining ECCS train injecting into three (3) loops only (No ECCS injection in the former cold leg break loop, the Safety Injection (SI) and accumulator are not reconnected here),
- Spilling into containment due to SI flow,
- Reactor Coolant Pumps (RCPs) tripped to simulate Loss of Offsite Power (LOOP) conditions.

The model used for this analysis was originally set up for a cold leg break and was not changed for the pressurizer surge line break. Therefore, the first three (3) assumptions are conservative for this analysis.

The pressurizer surge line break evaluation was performed with and without EDG start/load delay. A 60-seconds delay was agreed upon and included in the study. The break flow area was then varied to accommodate a flow area variance of ± 20 %.

The following acceptance criteria are expected to be met:

- Loss of inventory through the break is replenished by a steady cooling injection flow.
- No core uncovery.
- No deviance from the 10 CFR 50.46 limits.

3.3 PRESSURIZER SURGE LINE BREAK TRANSIENT DISCUSSION

Section 3.3.1 will describe the results for the pressurizer surge line break base case (C_d = 1.0) with and without EDG start/load delay. Section 3.3.2 will then discuss the effects of flow area variance.

The surge line diameter was assumed to be 0.958 feet. A total of six (6) cases were run for the three (3) C_d s and the presence of EDG start/load delay.

3.3.1 EDG Start/Load Delay Transient Discussion

The response of the RCS to a pressurizer surge line break with a discharge coefficient of 1.0 with and without EDG start/load delay is provided below in Figures 3.3.1-1 through 3.3.1-8.

The surge line break occurs at the beginning of the transient. The accumulators come online at approximately 100 sec, when the pressure reaches a level of 639.5 psia. Figure 3.3.1-1 shows the pressure history at the upper plenum location. From this plot, it is noted that the system depressurizes quickly until about 200 seconds at which point, the system stabilizes to a low plateau of about 50 psia.

At about 200 seconds, the accumulators run out and the system is then entirely cooled with the SI flow. This behavior is better observed in the break flow plot (Figure 3.3.1-2). For the first 100 seconds, the mass flow rate out of the break constantly decreases until the accumulators come on and replenish the flow throughout the system.

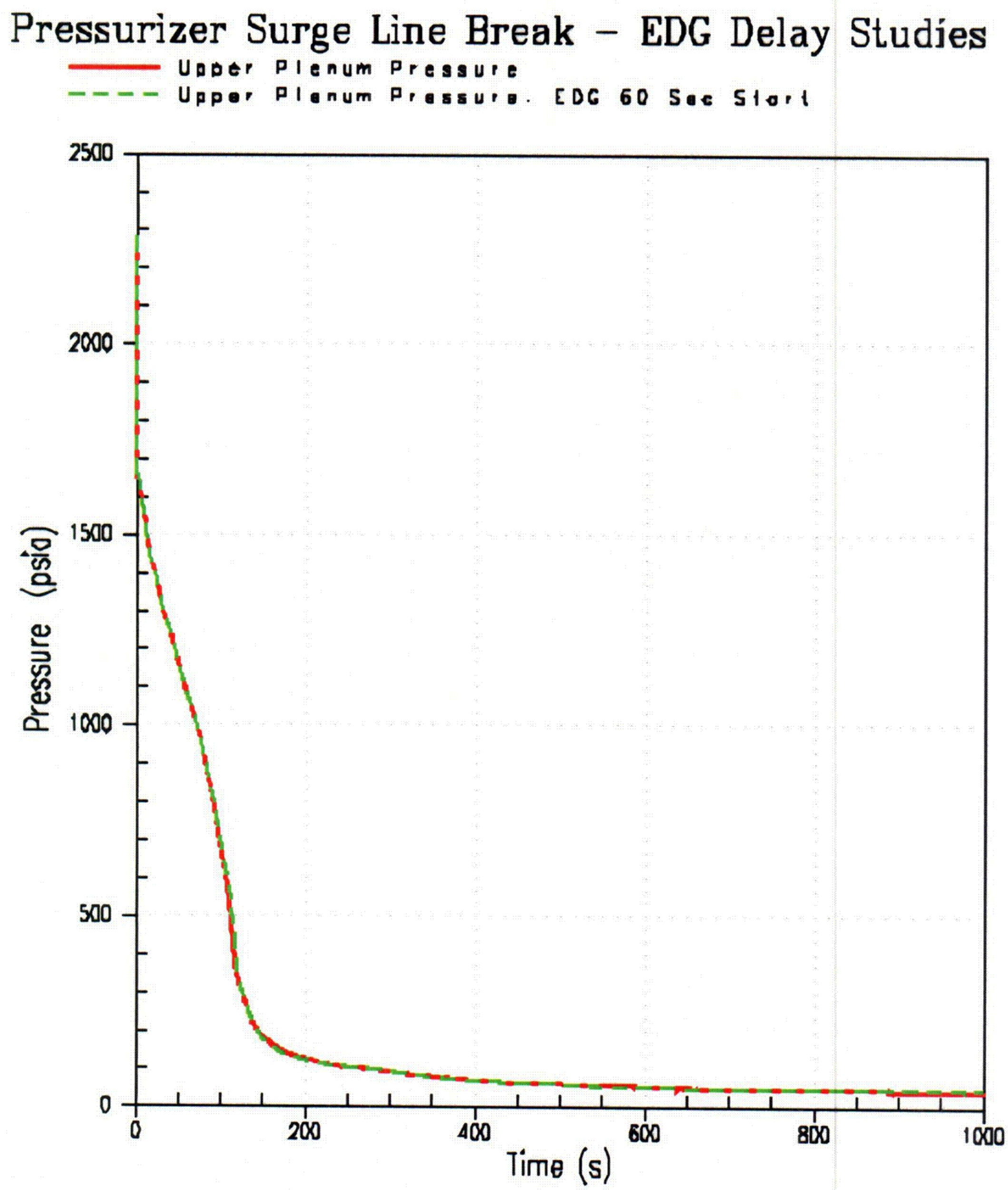
Figures 3.3.1-3 to 3.3.1-5 show the rapid mass flow loss and recovery in the vessel. From these three (3) plots, continuous upflow cooling is observed which contributes to the removal of stored energy before significant voiding. The total vessel water mass (Figure 3.3.1-3) is steadily increasing – a sign that the fluid loss through the break is replenished by an adequate SI injection flow.

No ECCS bypass occurs as shown in Figure 3.3.1-6.

Finally, there is no core heatup calculated as shown in the two (2) temperature plots (Figures 3.3.1-7 and 3.3.1-8). The average fuel temperature rapidly decreases to a constant value of roughly 300 °F. The dip in the curve observed at about 100 seconds coincides with the actuation of the accumulators. The maximum PCT (Figure 3.3.1-8) occurs at the beginning of the transient and then quickly drops to a plateau of about 250 °F. The PCT does not impact LBLOCA analysis; it is well below the 10 CFR 50.46 limit of 2200 °F.

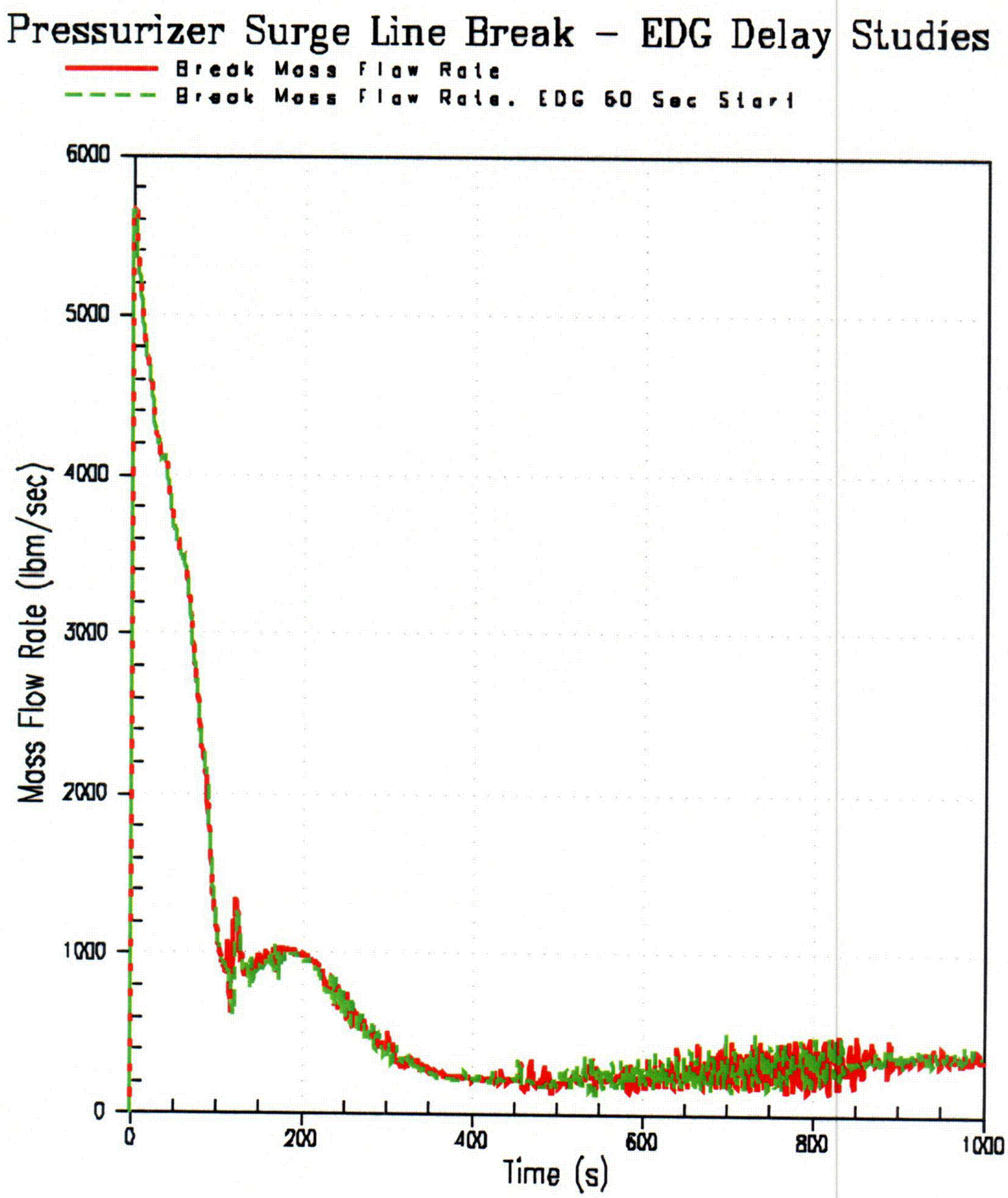
In conclusion, EDG start/load delay of 60 seconds does not significantly affect the results as seen from all the plots presented here. Figure 3.3.1-6, the total ECCS flow plot, best shows the effects of the diesel generator delay with a late SI actuation. However, the accumulators are sufficient to keep core covered without reliance on early actuation of pumped SI. In addition, peak pressures occur during blowdown, which is over before SI actuation even with the diesel generator delay. In summary, increasing EDG start up time has small impact on the PCT. The results indicate that a larger delay in EDG start/load can be accommodated.

Figure: 3.3.1-1



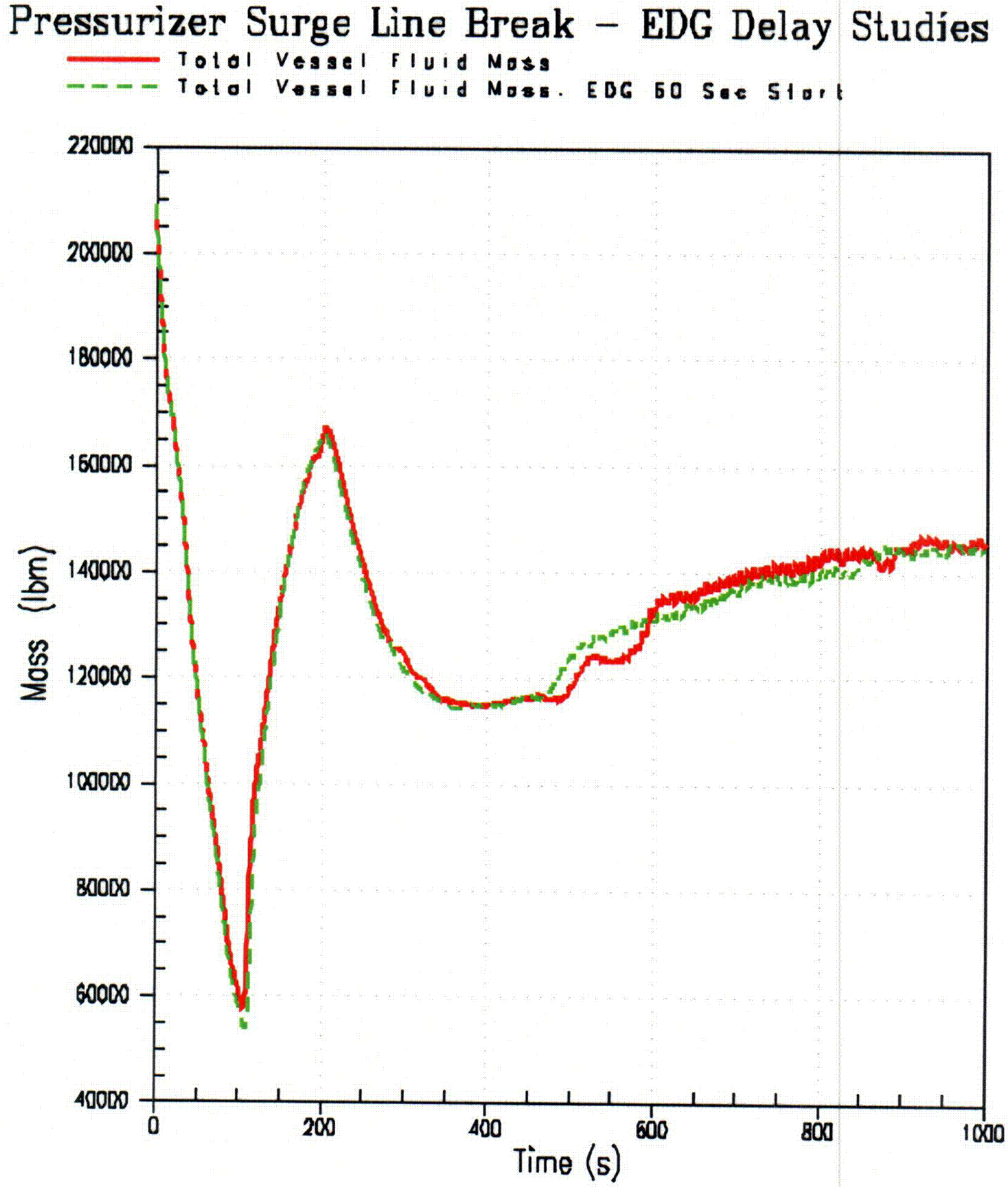
C18

Figure: 3.3.1-2



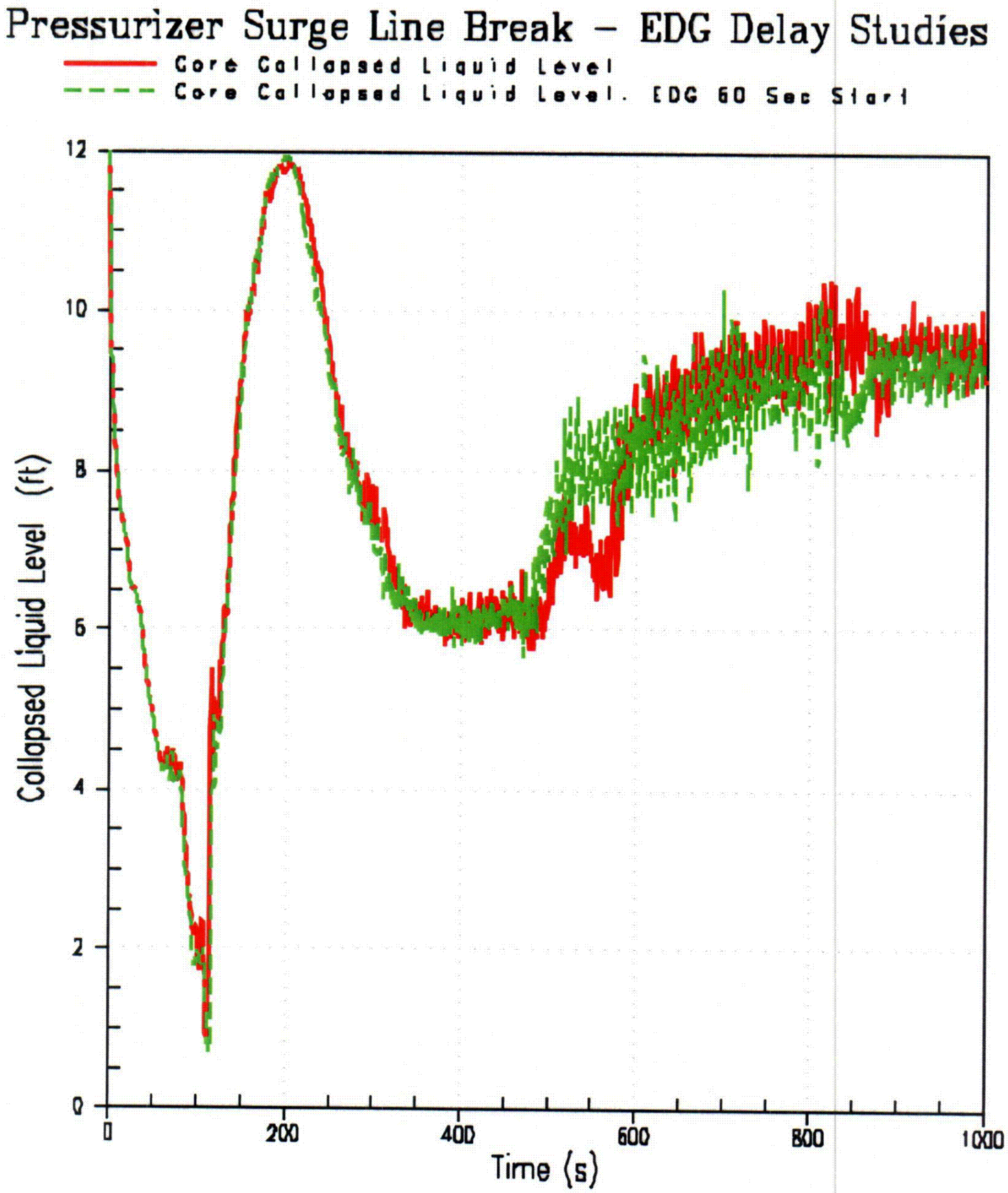
E19

Figure: 3.3.1-3



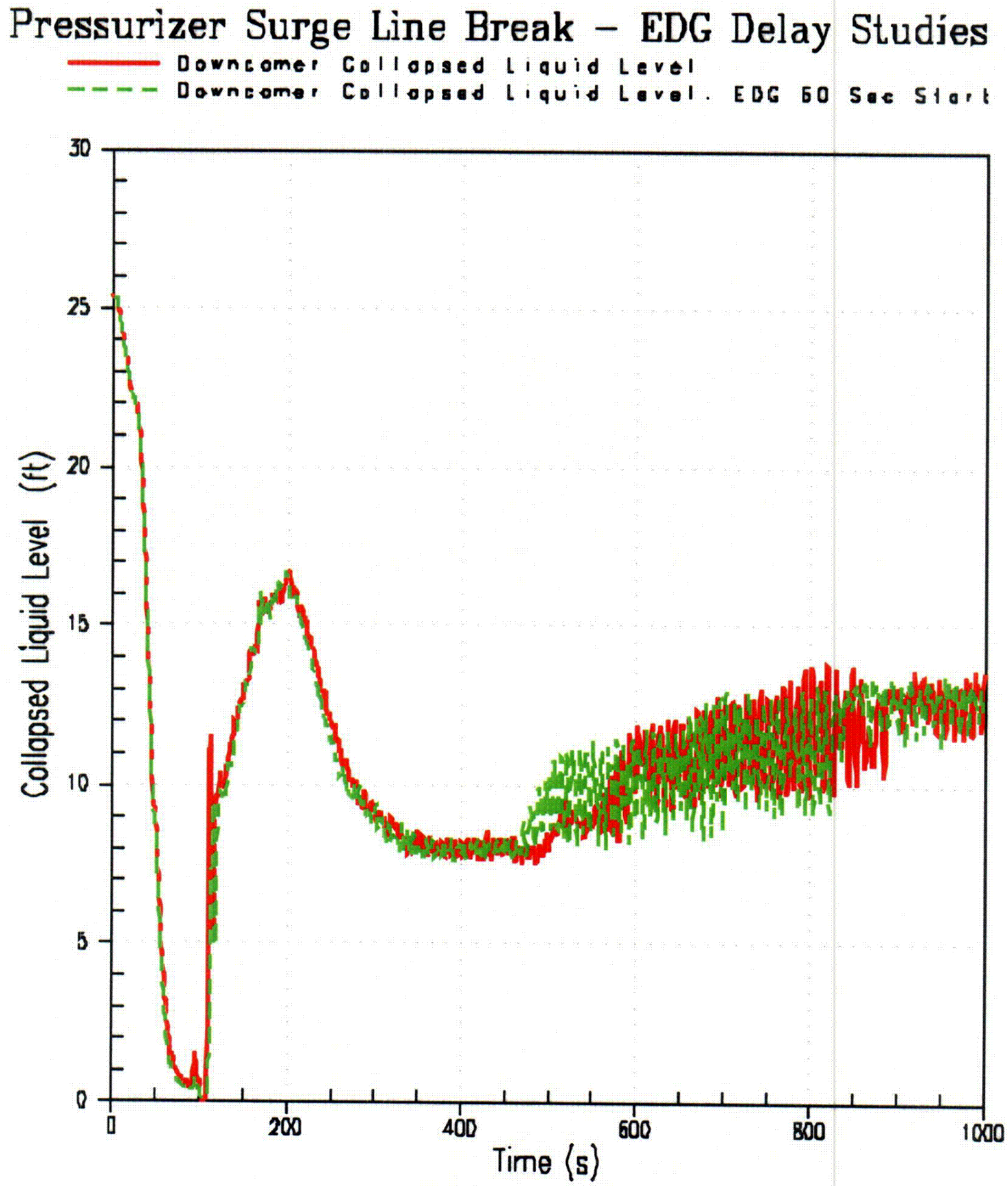
C20

Figure: 3.3.1-4



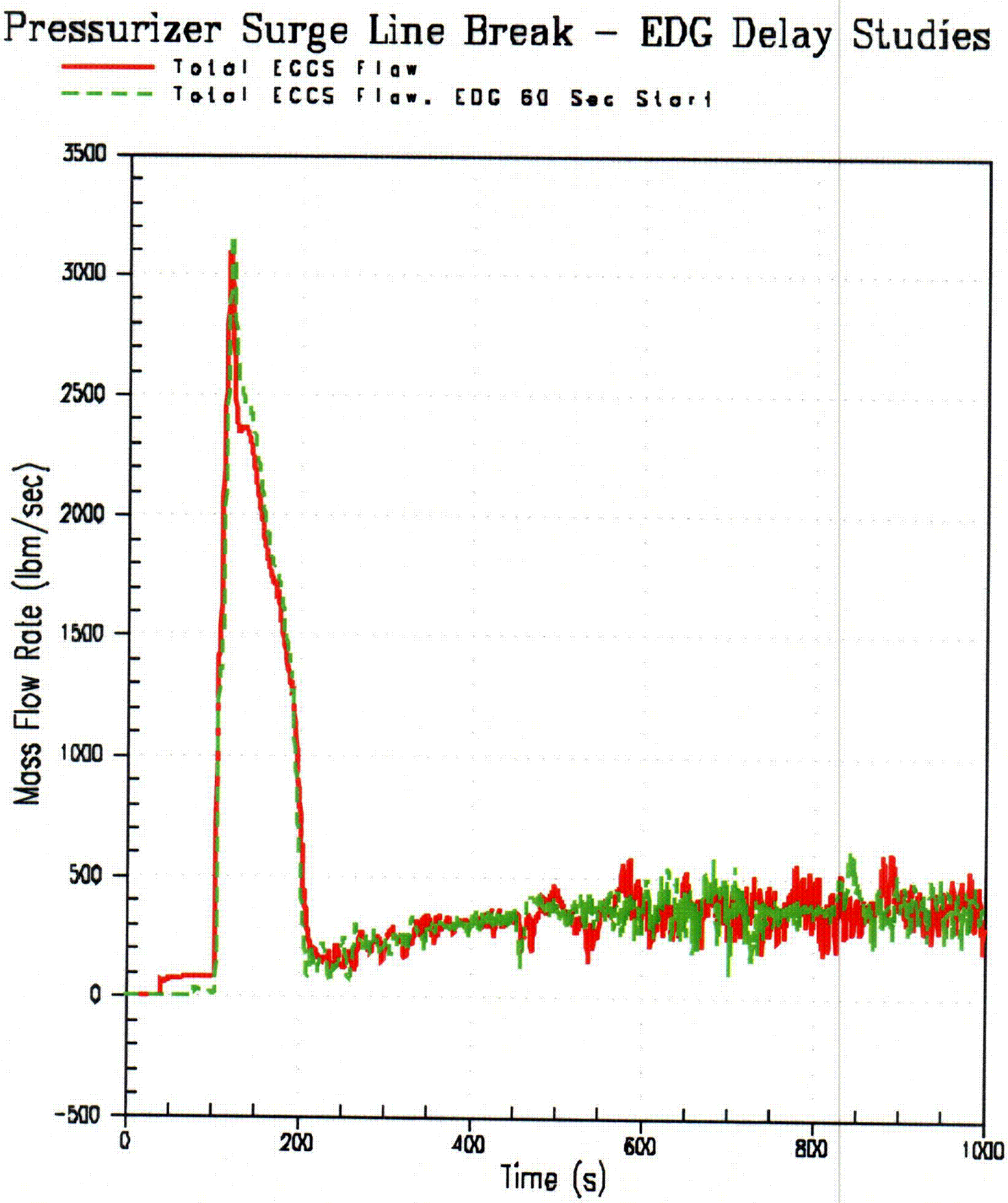
C21

Figure: 3.3.1-5



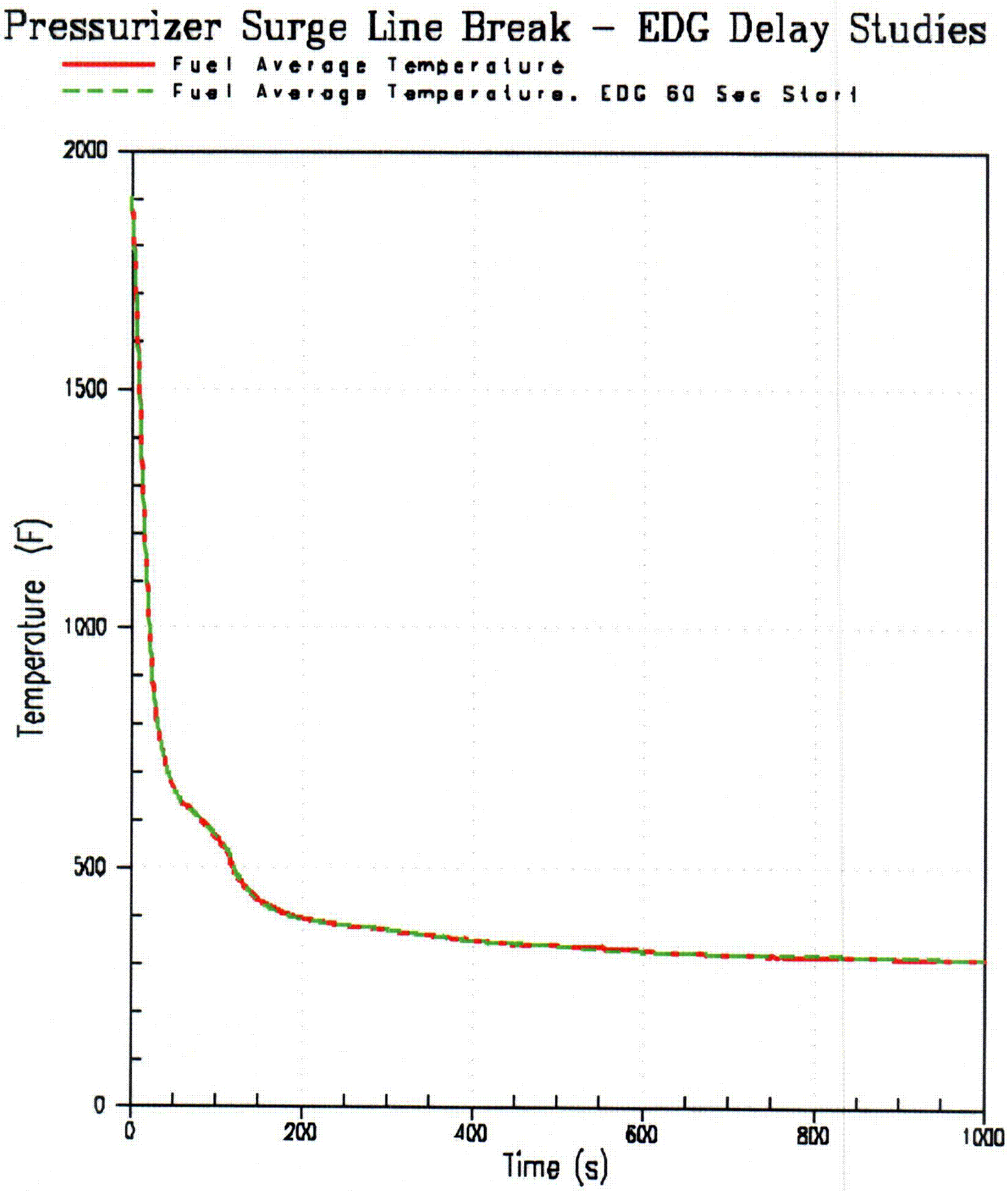
C22

Figure: 3.3.1-6



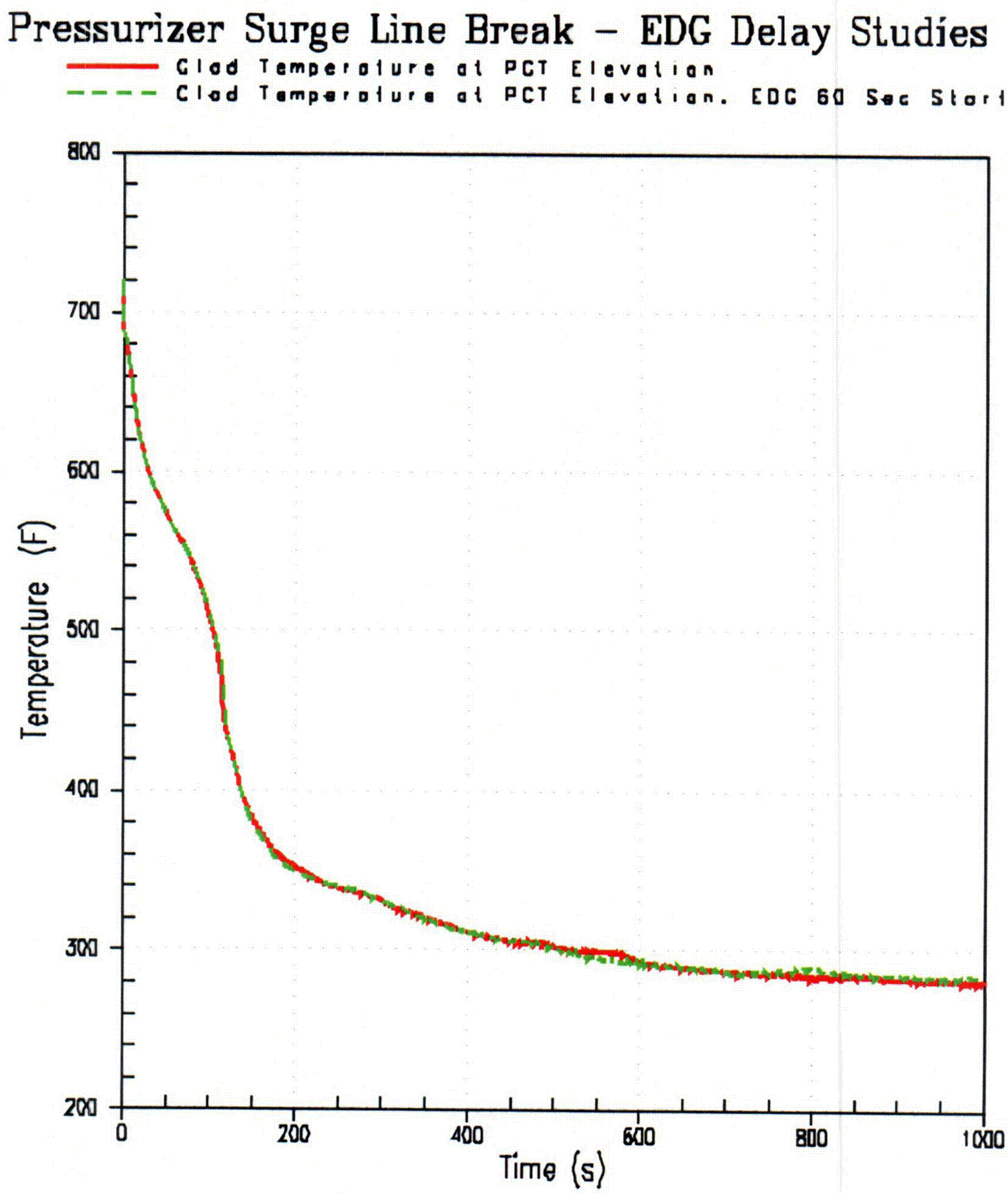
C23

Figure: 3.3.1-7



C24

Figure: 3.3.1-8



CZ5

3.3.2 Flow Area Variance Transient Discussion

To investigate the effects of different pressurizer surge line break sizes as part of the LBLOCA Redefinition program, the flow area is varied by ± 20%. For consistency, these flow variance studies are then rerun with the EDG start/load delay of 60 seconds. However, as shown in Section 3.3.1, the effects of the diesel generator startup delay are negligible and plots for these cases will not be shown here.

Figures 3.3.2-1 to 3.3.2-6 compare the results for the three (3) flow areas evaluated for the pressurizer surge line break.

From Figure 3.3.2-1, it is observed that the larger the discharge coefficient, the greater the mass flow rate discharged out of the break at the beginning of the transient. However, once the accumulators are actuated, the break size does not influence the transient to any further extent and the different cases are behaving in a similar manner for the rest of the transient. Similarly, less ECCS flow is needed to replenish the core for a smaller break size as observed from Figure 3.3.2-2. No ECCS bypass is also deduced from this plot. For $C_d = 0.8$, a second ECCS flow peak is observed at about 250 seconds. This is due to the system pressure falling below the limit of 639.5 psia. The accumulators are again actuated for a short period until the pressure in the system rises above the set limit.

The fluid behaviors for $C_d = 1.0$ and 1.2 are comparable as shown in Figures 3.3.2-3 to 3.3.2-5. Continuous upflow cooling is observed, contributing to the removal of stored energy before significant voiding. The total vessel water mass (Figure 3.3.2-3) is increasing at the same rate for both discharge coefficients. The fluid loss through the break is therefore replenished by an adequate safety injection flow. For $C_d = 0.8$, the vessel recovers later and less SI flow is injected in the core (Figure 3.3.2-4). In the downcomer however, the final liquid level is similar for all three (3) flow sizes (Figure 3.3.2-5).

Finally, from the PCT plot (Figure 3.3.2-6), it is concluded that there is no core heatup calculated. The maximum peak clad temperatures for all three (3) break sizes occur at the beginning of the transient and then quickly drops to plateaus ranging from 250 °F to about 325 °F. The smaller the break size, the larger the PCT observed at the end of the transient. This is due to the lower core recovery as described above. The PCTs observed do not impact LBLOCA analysis; the values are well below the 10 CFR 50.46 limit of 2200 °F.

Figure: 3.3.2-1

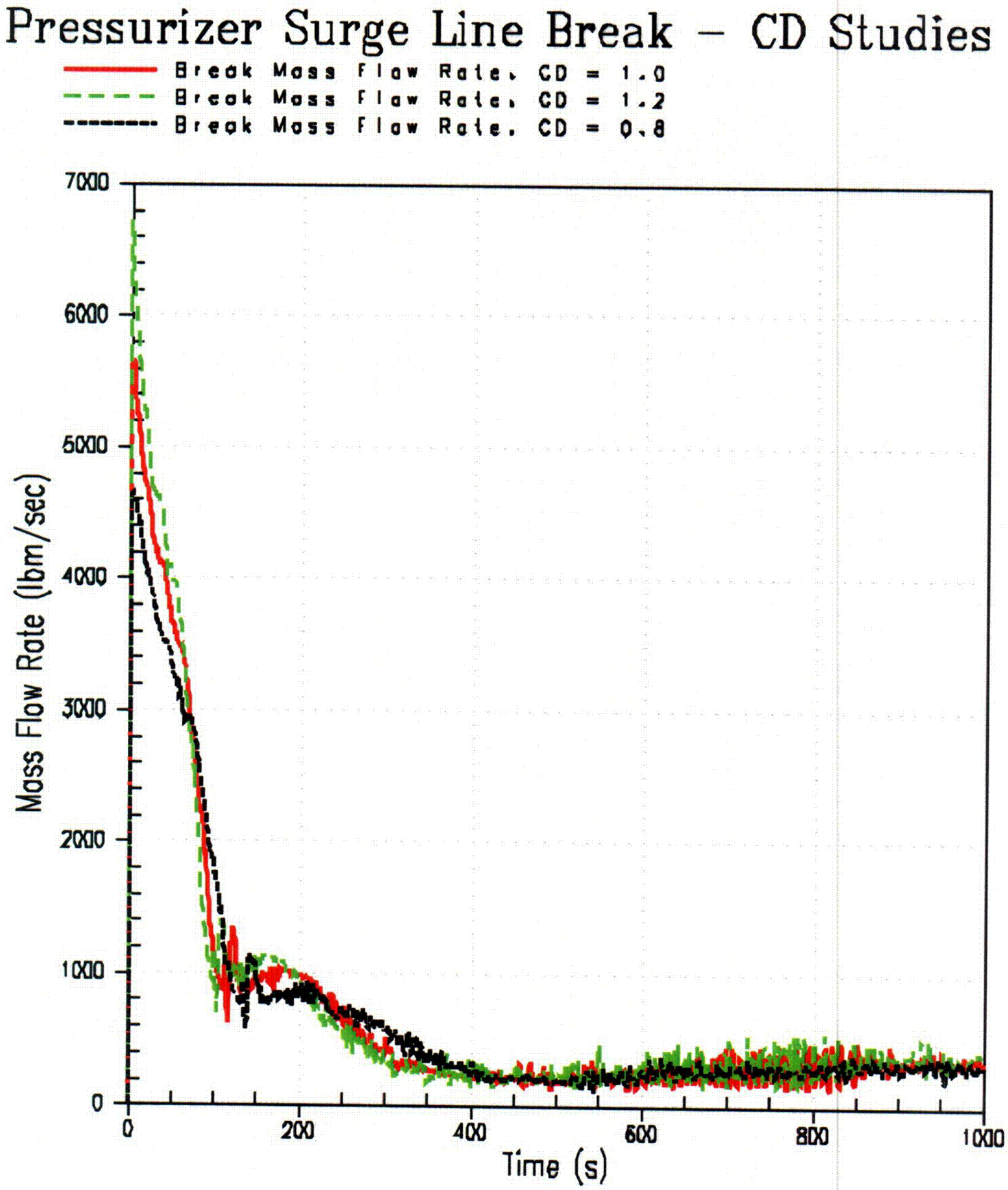


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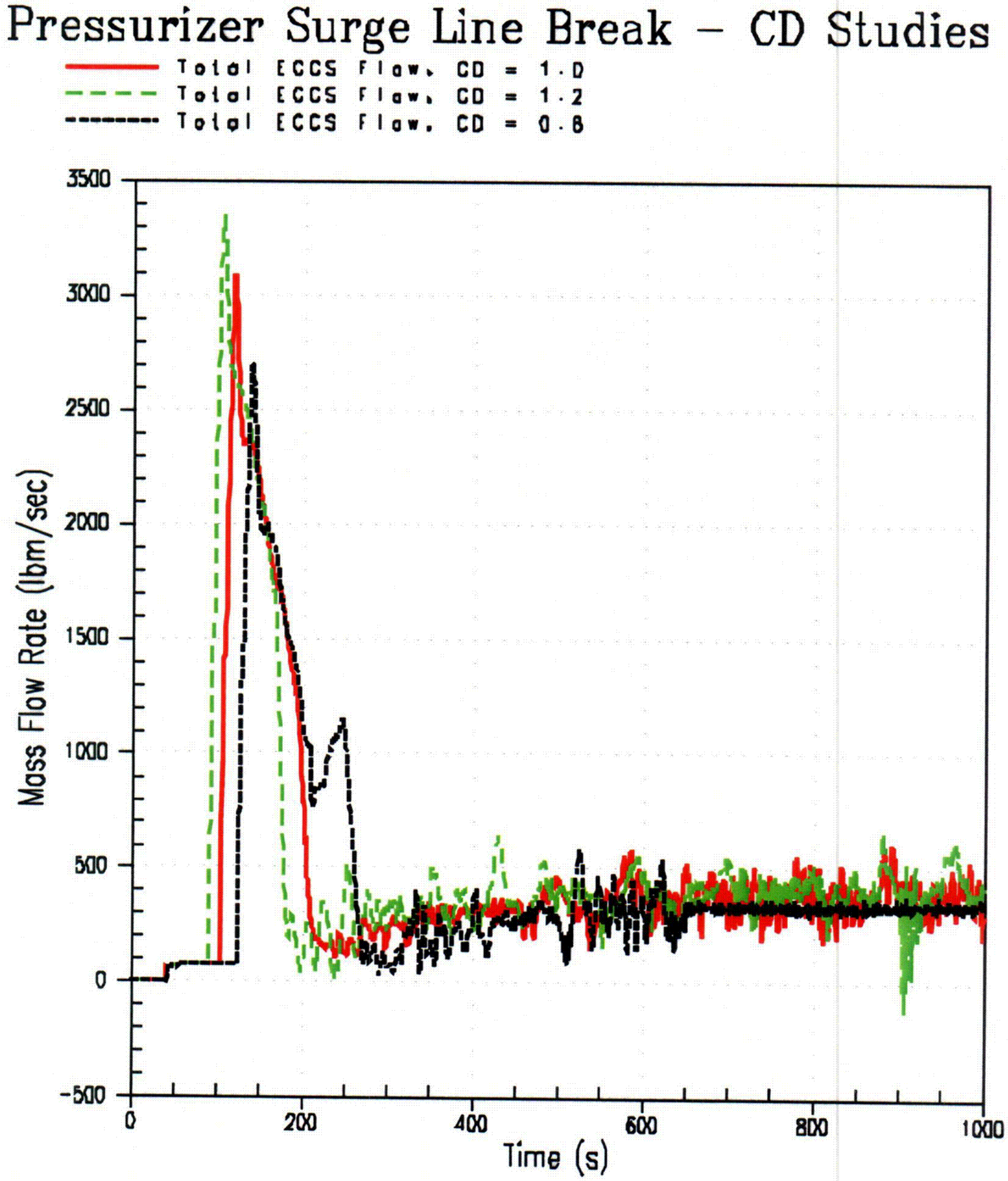
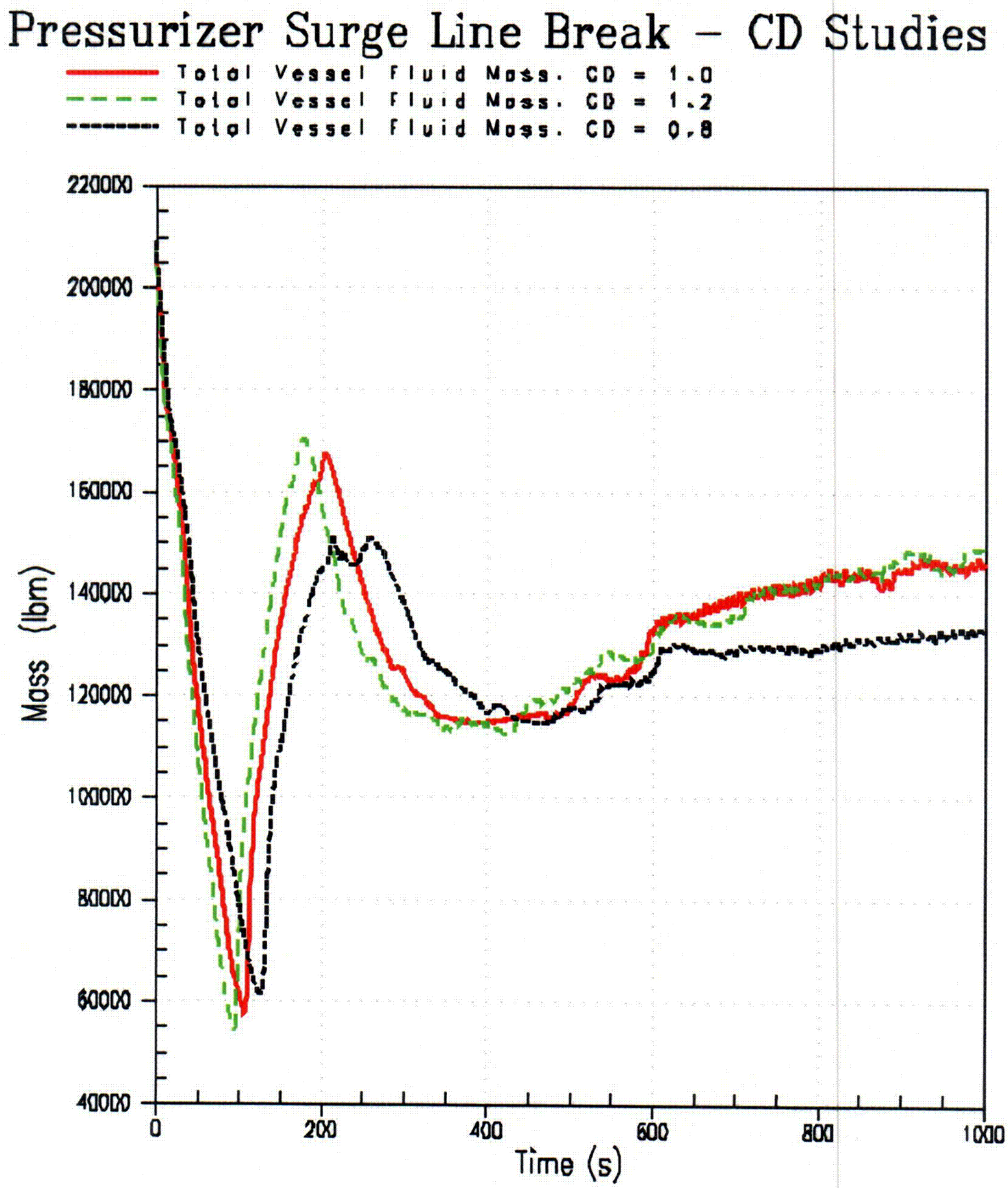
Figure: 3.3.2-2



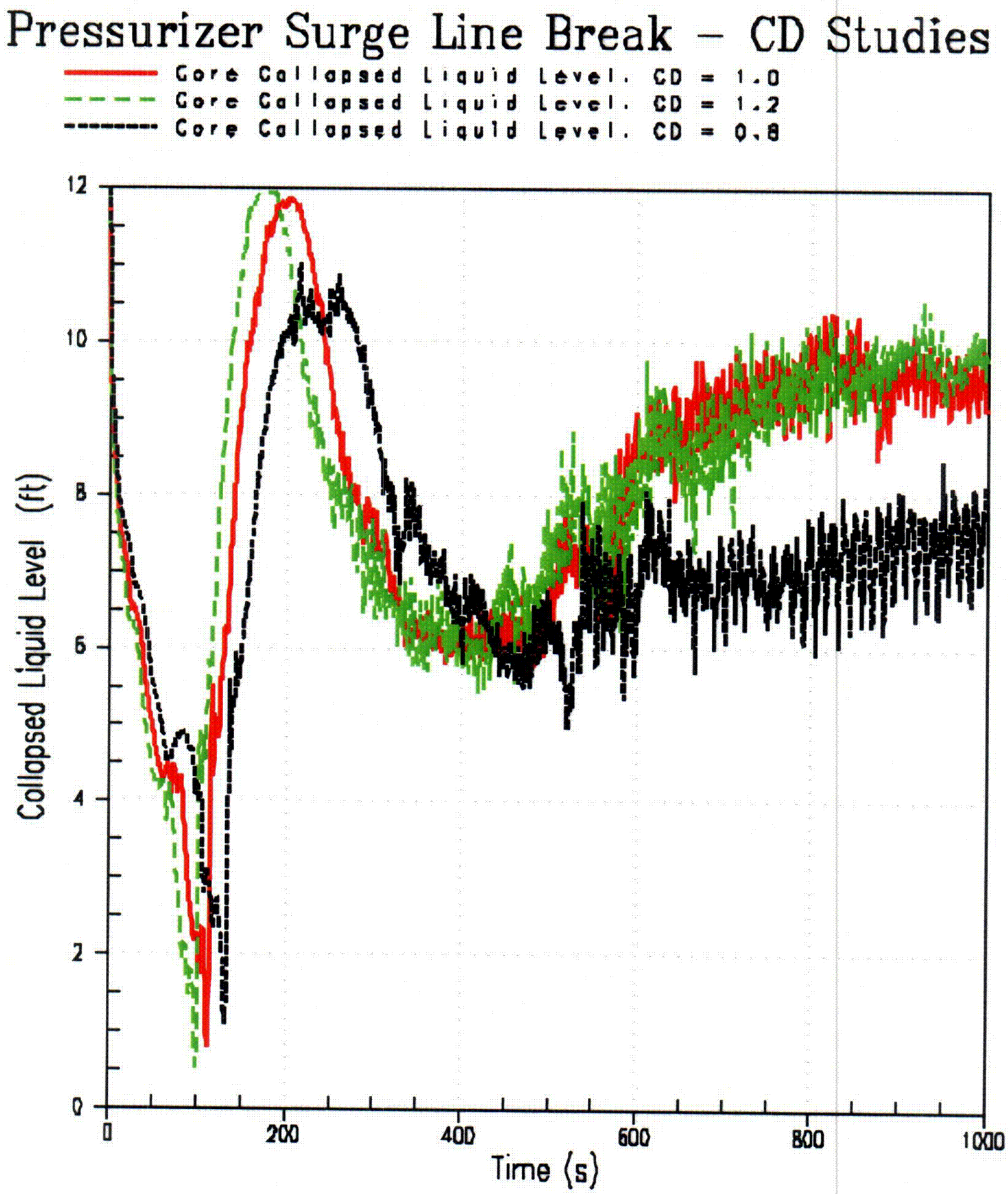
C27

Figure: 3.3.2-3



C28

Figure: 3.3.2-4



C29

Figure: 3.3.2-5

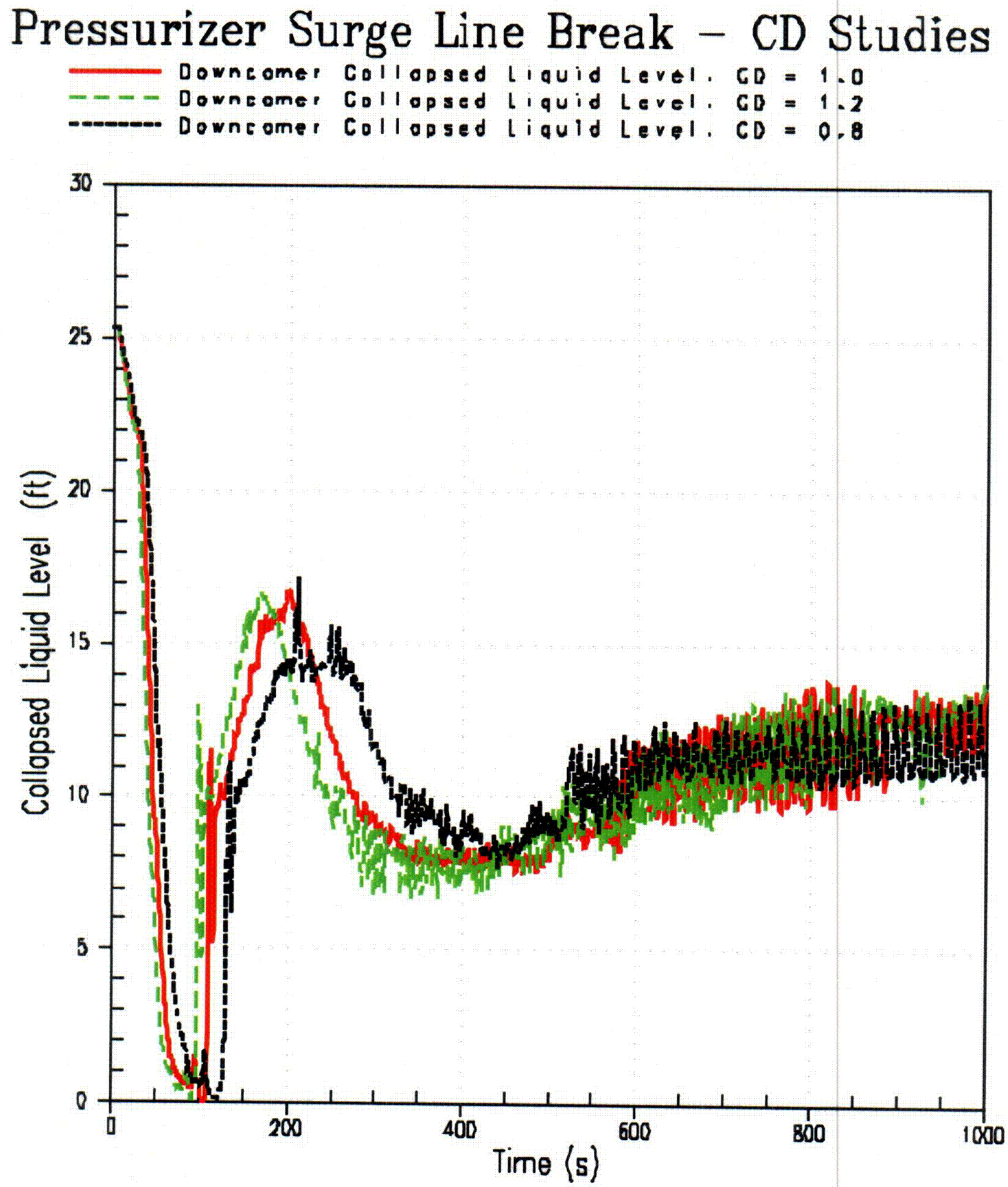


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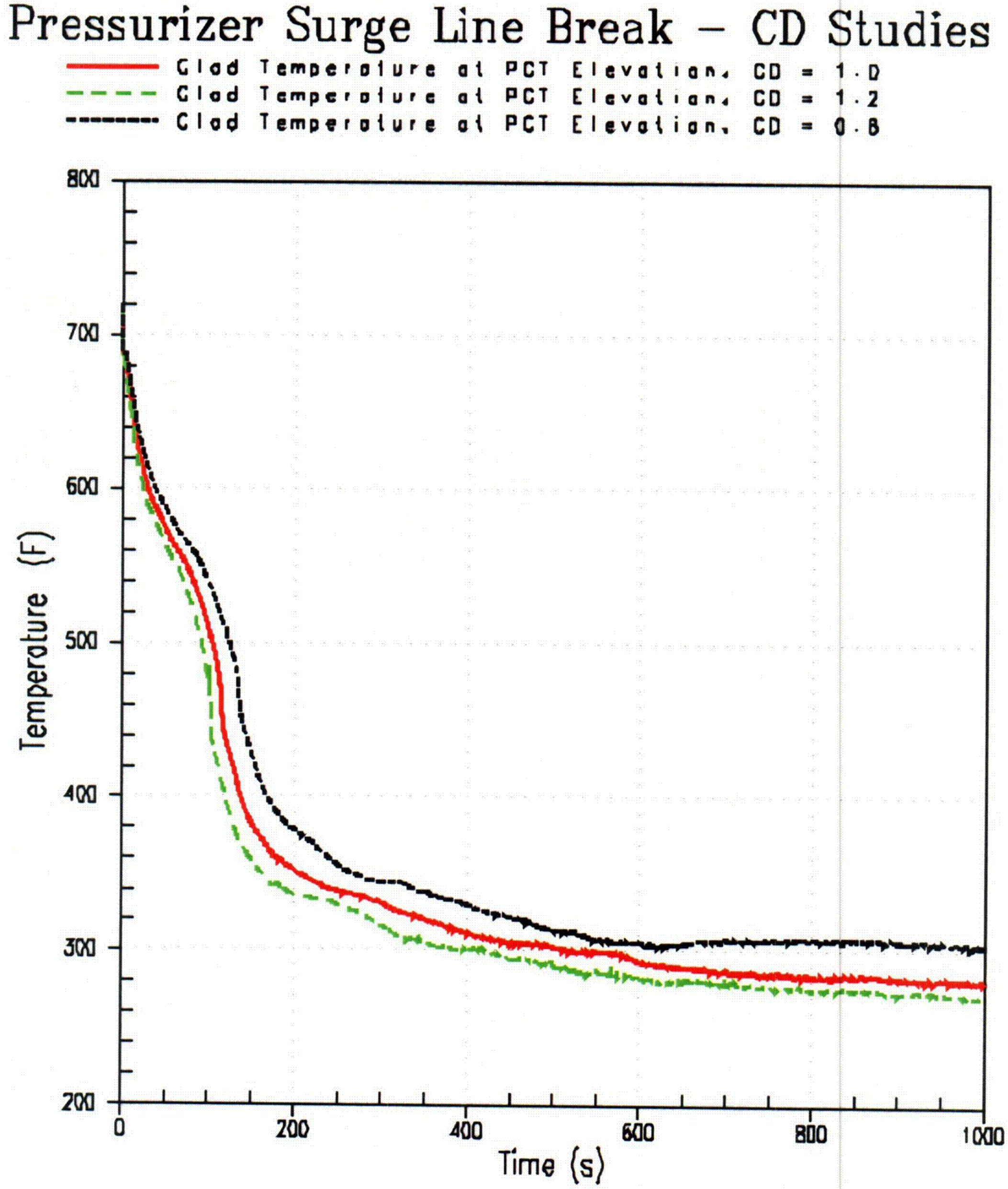
Figure: 3.3.2-6



C31

References

1. WOG-05-25, "Summary of the January 12, 13, and 14 2005 WOG / Industry Meeting with NRC to Discuss Regulatory Analysis for a 10 CFR 50.46 Rule Change," January 2005.

2. LTR-LIS-05-236, "Large Break LOCA Redefinition Program Input Assumptions," May 2005.

3. NUREG/IA-0127, "International Agreement Report – Reactor Safety Issues Resolved by the 2D/3D Program," July 1993.

Appendix B

Large Break LOCA Redefinition Program
Containment Response Analyses

Introduction and Background

Analyses are performed to demonstrate the containment heat removal systems (containment fan coolers and sprays) and containment structure can meet the design and licensing requirements to mitigate the effects of postulated design basis events. In all cases, the calculated containment pressure must remain less than the containment design pressure, and the calculated transient containment pressure and temperature must remain inside the equipment qualification envelope. Assuming a single failure of an active safety component, either a large double ended Loss of Coolant Accident (LOCA) or a Main Steam Line Break (MSLB) event will produce the limiting containment pressure and temperature transient response.

A complete loss of all offsite power coincident with the LOCA is assumed. Typically the limiting single failure is the failure of one of the emergency diesel generators, resulting in the loss of one train of safeguards equipment. The emergency diesel generators are actuated to provide power for the safety injection and containment heat removal systems. The combination of signal delay plus diesel delay and additional delays in starting the pumps and fans affect the start times of these cooling systems.

Typically, either the Double Ended Hot Leg (DEHL) or Double Ended Pump Suction (DEPS) LOCA produces the highest calculated containment pressure for the LOCA event. The containment peak pressure for a DEHL LOCA occurs during the blowdown phase of the LOCA event, before the safety injection or containment heat removal systems can be activated. The containment peak pressure for a DEPS LOCA can occur during either the blowdown or the long-term cooling phase of the LOCA event, depending on the capability of the containment heat removal systems.

As part of the evaluation effort for the large break LOCA redefinition program, Westinghouse performed containment response analyses to determine the impact of changing the allowed diesel startup delay time and to either delay or eliminate the containment sprays in the dry containment design. The containment response analyses considered LOCA events initiated from either a postulated large DEPS break, a double ended accumulator line break or a double ended pressurizer surge line break. A generic GOTHIC 4-loop dry containment plant model was used to perform the containment response analyses for this evaluation.

LOCA Mass and Energy Release Calculations

The DEPS mass and energy releases used for the large break LOCA redefinition program containment response evaluation analyses are presented in Figures 1 and 2. The calculation of the DEPS LOCA mass and energy releases was performed using the NRC approved methodology described in WCAP-10325-P-A. The SATAN78 code was used to calculate the blowdown phase mass and energy releases, the REFLOOD10325 code was used to calculate the reflood phase mass and energy release, and the EPITOME code was used to calculate the post-reflood and long-term cooling phase mass and energy releases.

The Steam Generator (SG) fluid/metal energy and Reactor Coolant System (RCS) metal energy release rates, along with the core decay heat generation rate, decrease with time. A non-mechanistic assumption for the release of the SG fluid/metal energy and the RCS metal energy is used in the REFLOOD10325 and EPITOME codes. All of the SG fluid/metal energy and RCS metal energy is assumed to be released to the containment in the first 3600 seconds of the event. This assumption puts a conservatively high heat load on the containment heat removal system during the first hour of the DEPS LOCA event. This assumption also helps maximize the calculated containment pressure and temperature during the first hour of the LOCA event.

The calculation of the accumulator line break mass and energy releases was performed using the NOTRUMP code. NOTRUMP is typically used to perform small break LOCA thermal-hydraulic analyses for Peak Clad Temperature (PCT). NOTRUMP uses a nodal network to model the RCS and is capable of calculating reasonable accumulator line break mass and energy releases.

The accumulator line break mass and energy releases used for the large break LOCA redefinition program containment response evaluation analyses are shown in Figures 3 and 4. The NOTRUMP releases from the small break LOCA PCT evaluation model were used as is (without biasing) for the containment response calculation.

The calculation of the pressurizer surge line break mass and energy releases was performed using the W-COBRA/TRAC (WCT) and GOTHIC computer codes; WCT was used to calculate the hot leg side mass and energy releases and GOTHIC was used to calculate the pressurizer side mass and energy releases. WCT is typically used to perform the large break LOCA thermal-hydraulic analyses for PCT. WCT uses a nodal network to model the RCS and is capable of calculating reasonable hot leg break mass and energy releases. GOTHIC is typically used to perform the containment response analyses. GOTHIC has a flexible noding structure and break flow modeling capabilities, so it is capable of calculating reasonable pressurizer side break blowdown mass and energy releases.

The pressurizer surge line break mass and energy releases used for the large break LOCA redefinition program containment response evaluation analyses are shown in Figures 5 and 6. The WCT hot leg releases from the large break LOCA PCT evaluation model were used as is (without biasing) for the containment response calculation. Likewise, the GOTHIC calculated pressurizer blowdown mass and energy releases were not biased for the containment response calculation.

Containment Model Description

A generic GOTHIC 4-loop dry containment plant model was used to perform the containment response analyses for this evaluation. The containment was modeled with a single lumped parameter volume containing 15 heat sinks and a fan cooler component. Boundary conditions were used to input the break mass and energy and provide containment spray. A separate volume representing the pressurizer was connected to the containment volume with a flow path representing the broken surge line for the surge line break analyses. The containment model noding diagram is shown in Figure 7.

The containment volume input value (2.5E6 ft^3) is typical for a large dry 4-loop containment design. The heat sink geometry data is given in Table 1 and the material property data is given in Table 2. The containment volume initial conditions were set to 14.7 psia, 120 °F and 50% relative humidity.

The fan cooler was modeled to start 60 seconds after the containment pressure exceeds 20.7 psia (6 psig). The fan cooler heat removal rate was modeled as a function of the vapor saturation temperature and is shown in Figure 8.

The containment spray was modeled to start 35 seconds after the containment pressure exceeds 44.7 psia (30 psig). The spray flow rate input value was 426.4 lb_m/s and the mean spray drop diameter input value was 526μ.

An 1800 ft^3 volume representing the pressurizer was connected to the containment volume for the surge line break analysis cases. The pressurizer was initialized with 60% water and 40% steam (by volume) at 2250 psia. The pressurizer temperature was initialized at 654 °F. The pressurizer was connected to the containment with a flow path representing the broken surge line. The surge line area input value was 0.7213 ft^2, the hydraulic diameter input value was 0.9583 ft, and the length input value was 20 ft. The GOTHIC break flow table option was used to calculate the critical flow rate through the broken surge line.

Containment Response for the DEPS LOCA

Four containment response sensitivity cases were run using the GOTHIC containment model with the DEPS LOCA mass and energy release as the break flow boundary condition. The base case (Case 1) used the standard input delay times to start the containment fan cooler and spray flow. Case 2 assumed there was no containment spray. Case 3 was the same as the base case, but assumed an additional 50-second delay in the Emergency Diesel Generator (EDG) start time. Case 4 was the same as Case 3, but without containment spray.

The containment pressure, temperature, and sump temperature results for the four DEPS LOCA cases are compared in Figures 9 through 11.

The calculated containment pressure, temperature and sump temperature were not very sensitive to increasing the EDG start time by 50 seconds. This can be seen by comparing the transient results for Cases 1 and 3 or Cases 2 and 4.

Not having containment spray for heat removal caused the containment heat-up period to be longer and the peak pressure to be higher. The peak pressure and temperature for Cases 2 and 4 occurred over 20 minutes later than Cases 1 and 3. The loss of spray resulted in over 7 psi increase in the calculated containment peak pressure and over 10 °F increase in the containment temperature. Lack of containment spray also caused the containment cool down to take longer.

Containment Response for the Accumulator Line Break

Six containment response sensitivity cases were run using the GOTHIC containment model with the accumulator line mass and energy release as the break flow boundary condition. The base case (Case 5) used the standard input delay times for the containment fan cooler and sprays. Case 6 assumed there was no containment spray. Case 7 was the same as the base case, but assumed an additional 50-second delay in the Emergency Diesel Generator (EDG) start time. Case 8 was the same as Case 7, but without containment spray.

Using a lumped parameter volume to model the containment is acceptable provided the containment atmosphere is well mixed throughout the transient. The containment will be well mixed during the blowdown portion of a large LOCA event. The containment will also be well mixed after the containment spray is initiated, which occurs shortly after the end of blowdown for a large break LOCA event. These conditions may not apply for smaller LOCA events such as the accumulator line break. The break energy may not be sufficient to mix the atmosphere during the blowdown and/or the containment pressure may not reach the spray actuation setpoint. However, it is felt that the containment will be adequately mixed based upon the containment pressures and temperatures calculated and discussed herein during the early phase of the accumulator line and surge line break events. In the longer term, the containment sprays and break flow and the containment fan coolers will maintain adequate mixing. The containment spray could also possibly be eliminated as part of the large break LOCA redefinition program. If this is the case, there may not be adequate mixing after the early phase of the accident. Therefore, in an effort to address the impact using a lumped parameter volume to model a potentially less than well mixed containment, sensitivity cases were run in which the heat sink areas were reduced uniformly by 50%. Cases 9 and 10 were the same as Cases 6 and 8, respectively, but the containment heat sink areas were all reduced by 50%. It should be noted that this 50% is an arbitrary assumption and may not necessarily be appropriate for smaller breaks whenever containment sprays are not actuated.

The containment pressure, temperature, and sump temperature results for the six accumulator line break cases are compared in Figures 12 through 14.

The calculated containment pressure, temperature and sump temperature were not very sensitive (less than 1 psi or 1 °F) to increasing the EDG start time by 50 seconds. This can be seen by comparing the transient results for Cases 5 and 7, Cases 6 and 8, or Cases 9 and 10.

Not having containment spray for heat removal caused the containment heat up period to be longer and the peak pressure to be higher. The peak pressure and temperature for Cases 6 and 8 occurred approximately 10 minutes later than Cases 5 and 7. Without spray cooling, the calculated containment peak pressure increased by over 5 psi and the peak containment temperature increased by over 5 °F. Not having containment spray also caused the containment cool down to take longer.

Assuming less than perfect mixing of the containment atmosphere due to the smaller break size and no containment spray, as simulated with the reduced containment heat sink area, had a large impact on the transient results. The calculated containment peak pressure calculated for Cases 9

and 10 increased by about 10 psi when compared to Cases 6 and 8 and by about 15 psi when compared to Case 5, the base case for the accumulator line break.

Containment Response for the Pressurizer Surge Line Break

Six containment response cases were run using the GOTHIC containment model with the pressurizer surge line mass and energy release as the break flow boundary condition. The base case (Case 11) used the standard input delay times for the containment fan cooler and sprays. Case 12 assumed there was no containment spray. Case 13 was the same as the base case, but assumed an additional 50-second delay in the Emergency Diesel Generator (EDG) start time. Case 14 was the same as case 13, but without containment spray. To address the containment perfect mixing assumption, as discussed above, Cases 15 and 16 were the same as Case 12 and 14 respectively, but the containment heat sink areas were all reduced by 50%.

The containment pressure, temperature, and sump temperature results for the six pressurizer surge line break cases are compared in Figures 15 through 17.

The calculated containment pressure, temperature and sump temperature were not very sensitive to increasing the EDG start time by 50 seconds. This can be seen by comparing the transient results for Cases 11 and 13, Cases 12 and 14, or Cases 15 and 16.

Not having containment spray for heat removal did not affect the containment heat up period or peak pressure, since it occurred just before spray was initiated. The containment cool down did take longer without spray heat removal.

Assuming less than perfect mixing of the containment atmosphere and no containment spray, as simulated with the reduced containment heat sink area, had a large impact on the transient results. The calculated containment peak pressure calculated for Cases 15 and 16 increased by 4 to 5 psi when compared to Cases 12 and 14, and by about 10 psi when compared to Case 11, the base case for the pressurizer surge line break.

Summary and Conclusions

The peak pressure results of the containment response analysis cases are summarized in Table 3.

The DEPS LOCA case remained bounding from the containment peak pressure perspective when compared to the smaller accumulator line break and pressurizer surge line break cases with the same assumptions regarding containment spray and EDG delay time.

The containment peak pressure is not sensitive to the EDG startup time. If the EDG startup time were permitted to be increased from 10 seconds to 60 seconds, the calculated containment peak pressure would increase by less than 1 psi due to the delay in actuating the fan coolers and spray.

Without spray cooling, the containment pressure and temperature continue to increase until the fan cooler energy removal rate can match the break energy release rate. This took approximately 20 minutes and resulted in a 5 to 7 psi increase in the peak containment pressure for the DEPS

LOCA and accumulator line break cases. The calculated peak pressure for the pressurizer surge line break case was not sensitive to the loss of spray cooling because the peak pressure occurred before spray actuation. The energy removal rate by the combination of containment heat sinks and fan coolers was able to exceed the break energy release rate within approximately 2 minutes for the pressurizer surge line break. In all cases, the containment pressure and temperature also took longer to cool down due to the lower energy removal rate without containment spray.

The loss of containment spray could result in a less than well mixed containment atmosphere. A 50% reduction in the containment heat sink area was arbitrarily used to estimate the impact of a less than well mixed containment atmosphere for one of the accumulator line break cases and one of the pressurizer surge line break cases without containment spray. When compared with the base case results, the combination of the loss of containment spray and the reduction in heat sink area caused the containment peak pressure to increase by about 15 psi in the accumulator line break case and by about 4 to 5 psi in the pressurizer surge line break case. The energy removal rate by the combination of the remaining containment heat sinks and fan coolers was able to exceed the break energy release rate within 3 minutes for the pressurizer surge line break case; therefore, the impact on the containment peak pressure was not as great as the accumulator line break.

The results and conclusions presented herein are not applicable to all of the different PWR containment designs. Some containment heat removal systems do not employ the safety grade fan coolers that were assumed for this evaluation and other containment designs employ ice to condense the steam released from the break. Plant specific analyses are recommended due to the differences in containment design and containment heat removal capabilities.

Table 1: Containment Heat Sink Geometry

		Area (ft2)	Sides	Paint[1] (in)	Primer (in)	Zinc (in)	SS Steel (in)	CS Steel (in)	Air Gap (in)	Concrete (in)	Total (in)
1	Shell	58807	1	0.0212	0.004			0.25	0.01	48	48.2852
2	Dome	30806	1	0.0212	0.004			0.25	0.01	36	36.2852
3	Unlined Concrete	65831	1							20.64	20.6400
4	SS Lined Concrete	7197	1				0.25		0.01	24	24.2600
5	GS Lined Concrete	6679	1			0.00132		0.0635	0.01	16.116	16.1908
6	Stainless Steel	18648	1				0.215				0.2150
7	Galvanized Steel	68451	1			0.00132		0.094			0.0953
8	CS w/o Paint	1769	1					0.25			0.2500
9	Painted CS	13450	1	0.0212	0.004			0.0835			0.1087
10	Painted CS	84088	1	0.0212	0.004			0.2			0.2252
11	Painted CS	40471	1	0.0212	0.004			0.338			0.3632
12	Painted CS	24306	1	0.0212	0.004			0.708			0.7332
13	Painted CS	11932	1	0.0212	0.004			1.343			1.3682
14	Painted CS	7805	1	0.0212	0.004			3.347			3.3722
15	CS Lined Concrete	6464	1	0.0212	0.004			0.25	0.01	24	24.2852

Table 2: Heat Sink Material Properties

	Conductivity (Btu/hr-ft-°F)	Density (lbm/cf)	Vol. Heat Capacity (Btu/cf-°F)	Specific Heat (Btu/lbm-°F)
Paint – Epoxy	0.97	49.9	49.9	1.0
Paint – Primer	0.63	21.7	21.7	1.0
Concrete	0.8	144	30.03	0.209
Carbon Steel	28.35	490	54.3	0.1108
Stainless Steel	8.4	488	53.9	0.1105
Zinc	64.8	446	40.9	0.0917
Air (gap)	0.0174	0.06	0.0145	0.241

Table 3: Summary of Results			
Case Number	Case Description	Peak Pressure (psia)	Time of Peak Pressure (sec)
1	DEPS LOCA – Base Case	58.5	25
2	DEPS LOCA – No Spray	65.6	1440
3	DEPS LOCA – EDG Delay	58.5	25
4	DEPS LOCA – EDG Delay, No Spray	65.9	1440
5	ACC Break – Base Case	47.0	560
6	ACC Break – No Spray	52.6	1075
7	ACC Break – EDG Delay	47.9	530
8	ACC Break – EDG Delay, No Spray	53.2	1110
9	ACC Break – No Spray, 50% Heat Sinks	62.7	1215
10	ACC Break – EDG Delay, No Spray, 50% Heat Sinks	63.6	1199
11	PSL Break – Base Case	47.0	125
12	PSL Break – No Spray	47.0	125
13	PSL Break – EDG Delay	47.4	125
14	PSL Break – EDG Delay, No Spray	47.4	125
15	PSL Break – No Spray, 50% Heat Sinks	51.5	155
16	PSL Break – EDG Delay, No Spray, 50% Heat Sinks	51.9	155

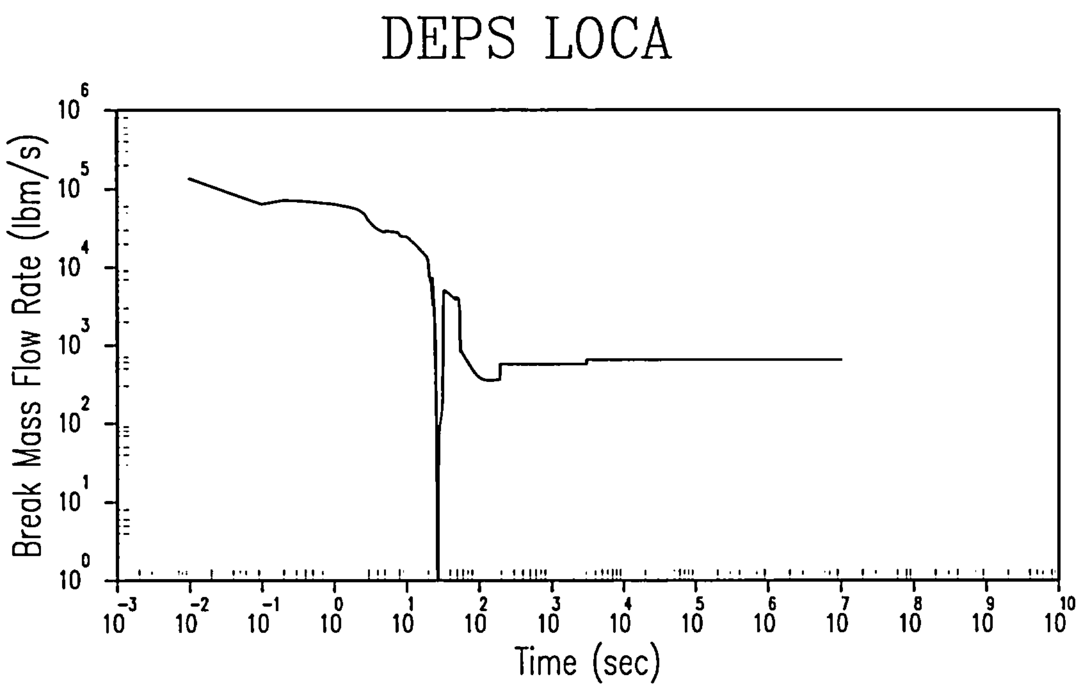


Figure 1: DEPS LOCA Break Mass Flow Rate

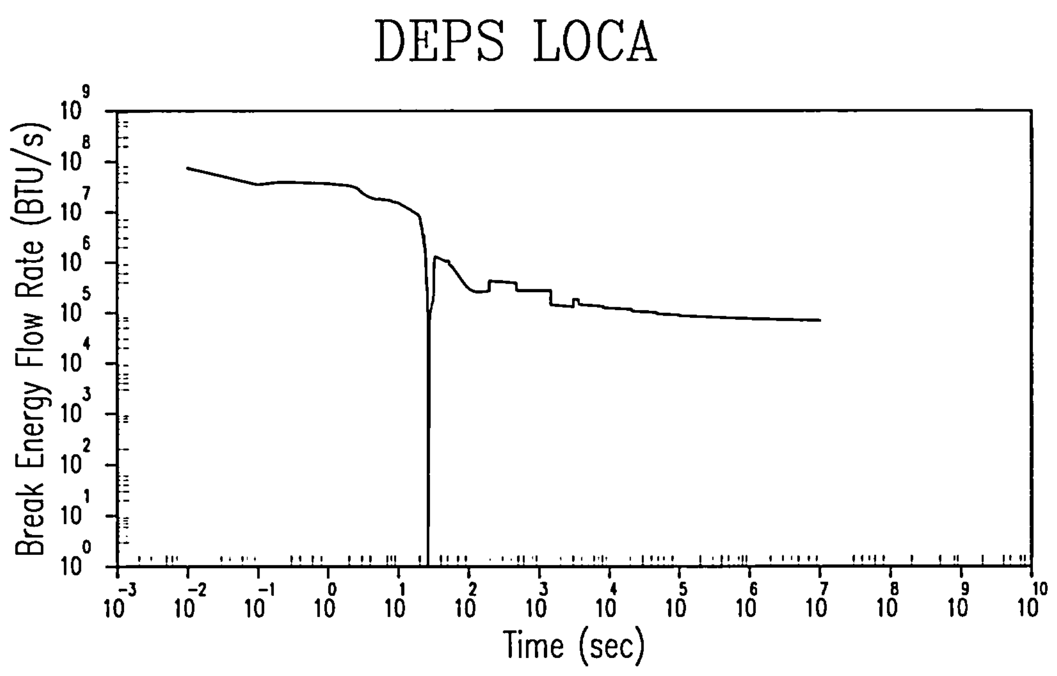


Figure 2: DEPS LOCA Break Energy Flow Rate

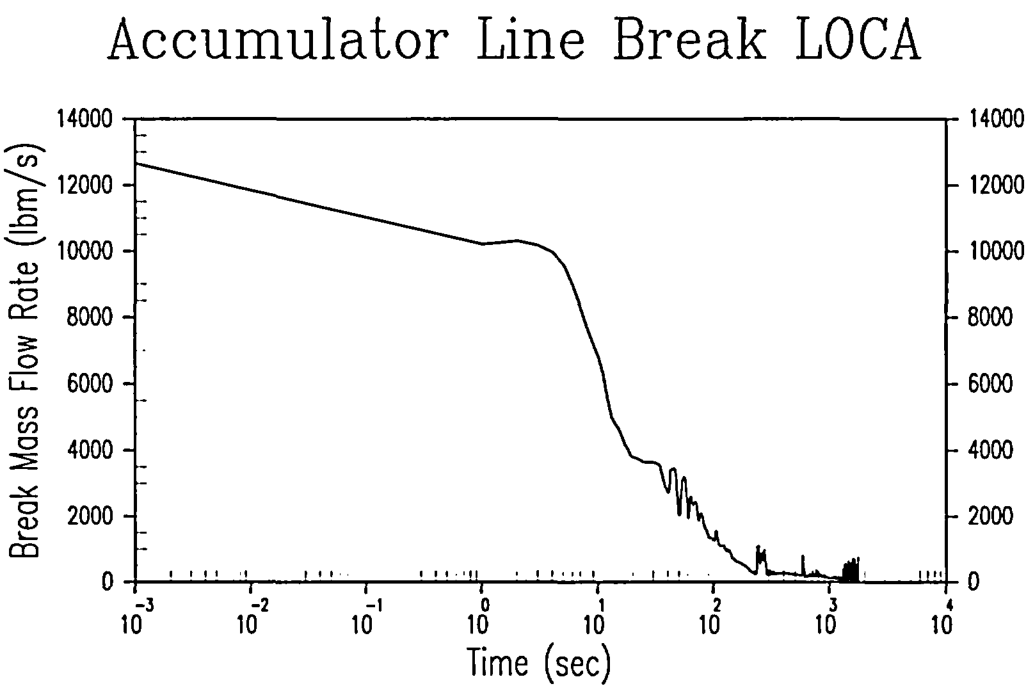


Figure 3: Accumulator Line Break Mass Flow Rate

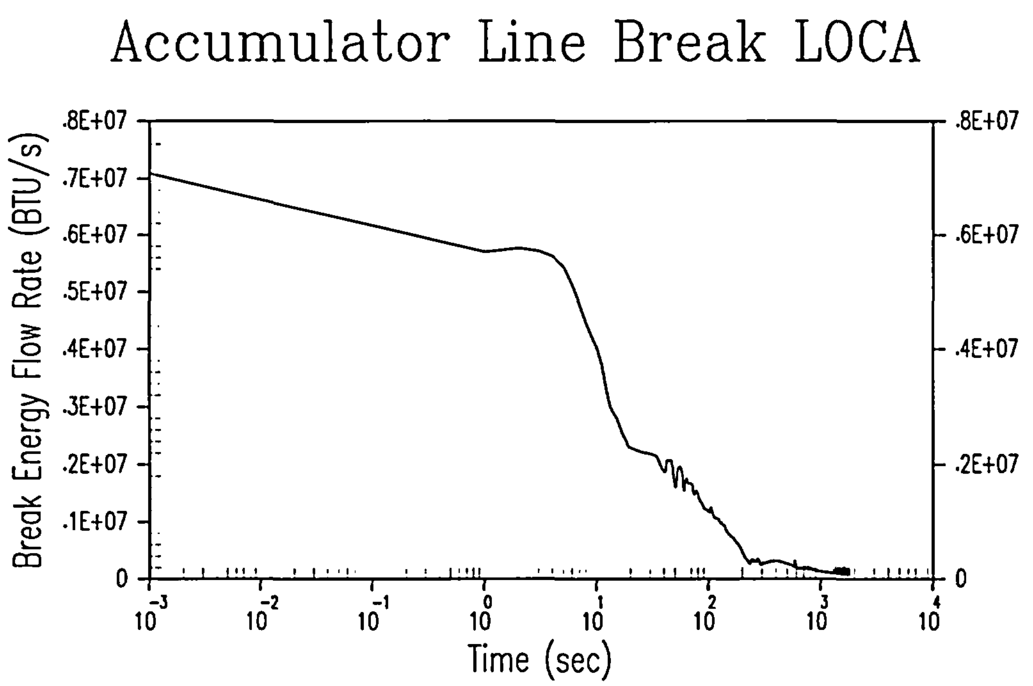


Figure 4: Accumulator Line Break Energy Flow Rate

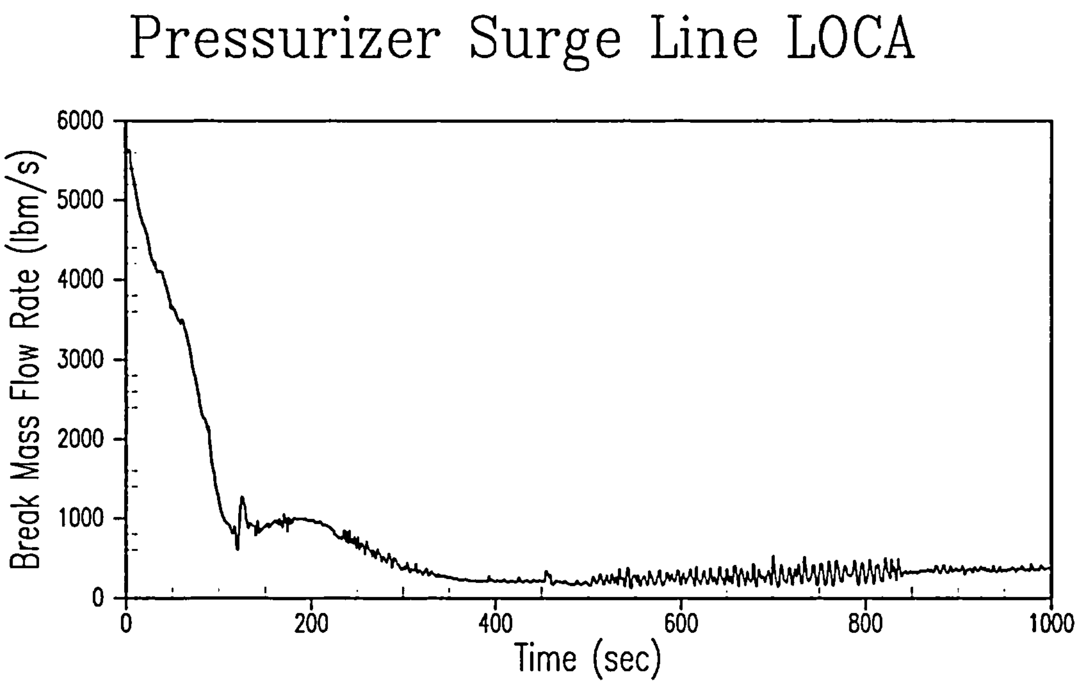


Figure 5: Pressurizer Surge Line Break Mass Flow Rate

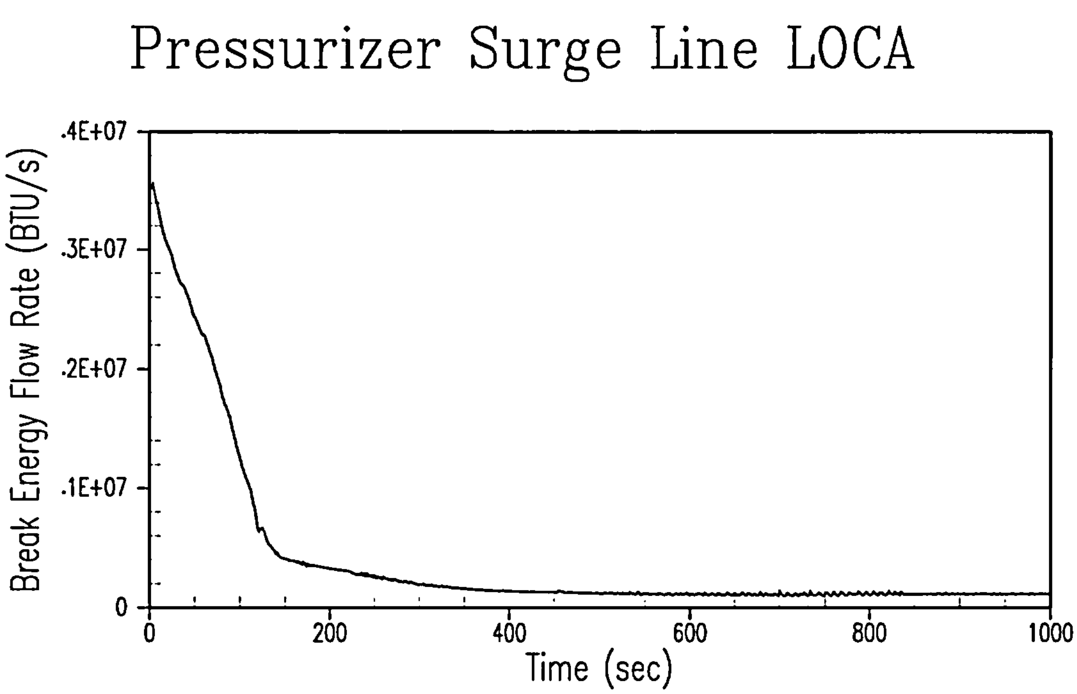


Figure 6: Pressurizer Surge Line Break Energy Flow Rate

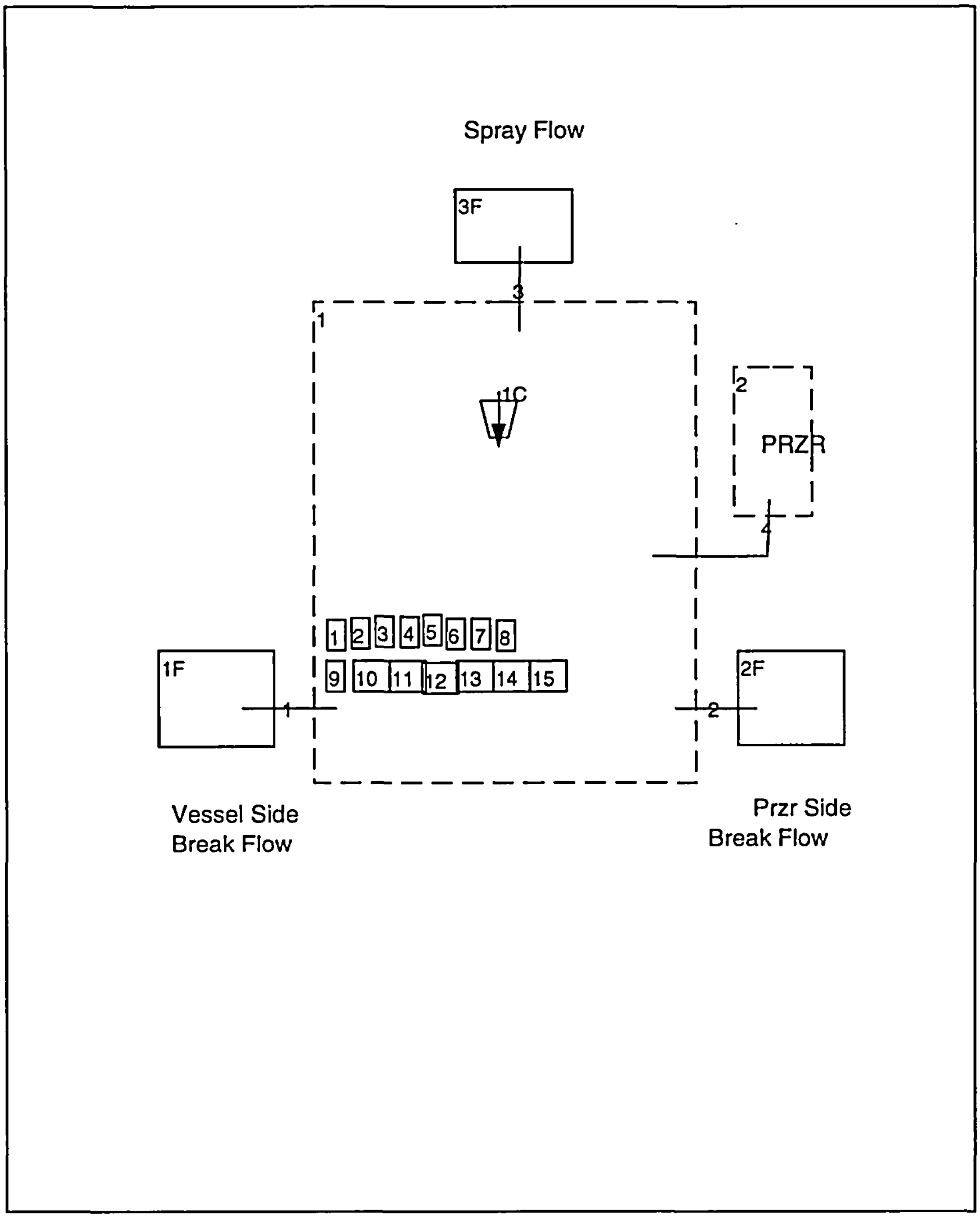


Figure 7: Containment Model Noding Diagram

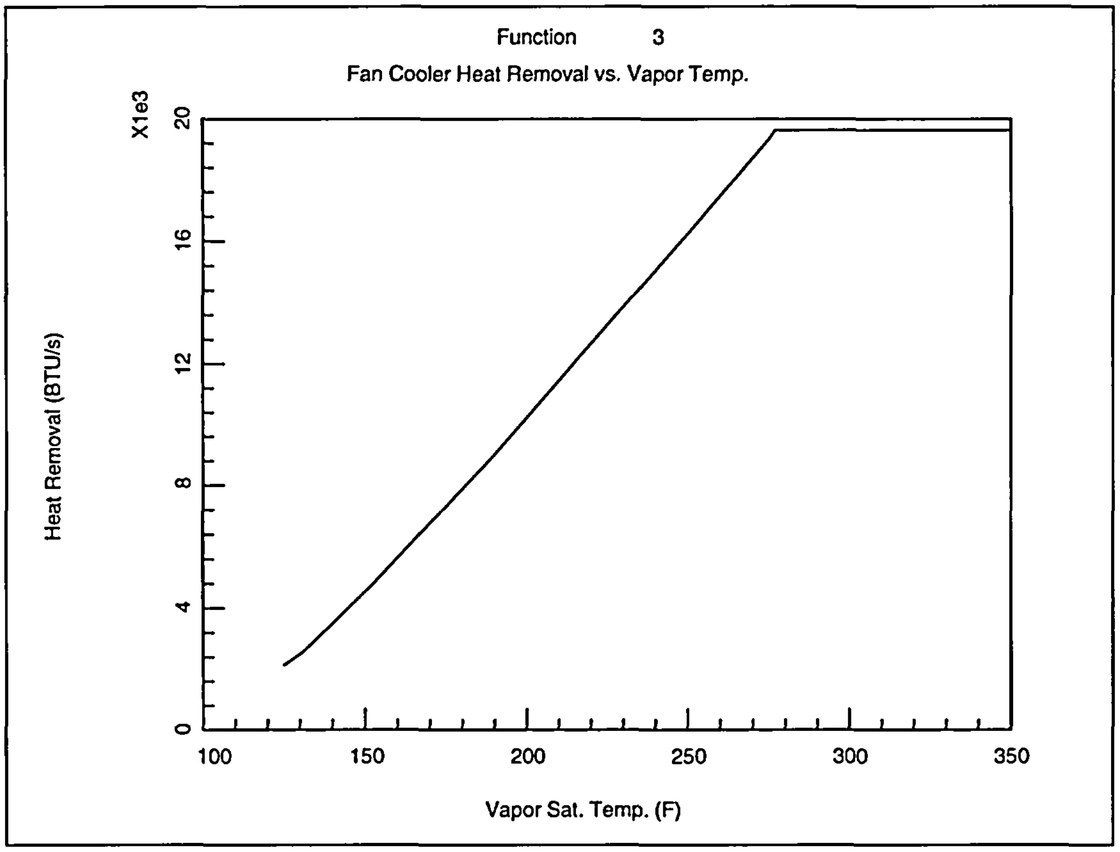


Figure 8: Fan Cooler Heat Removal Function

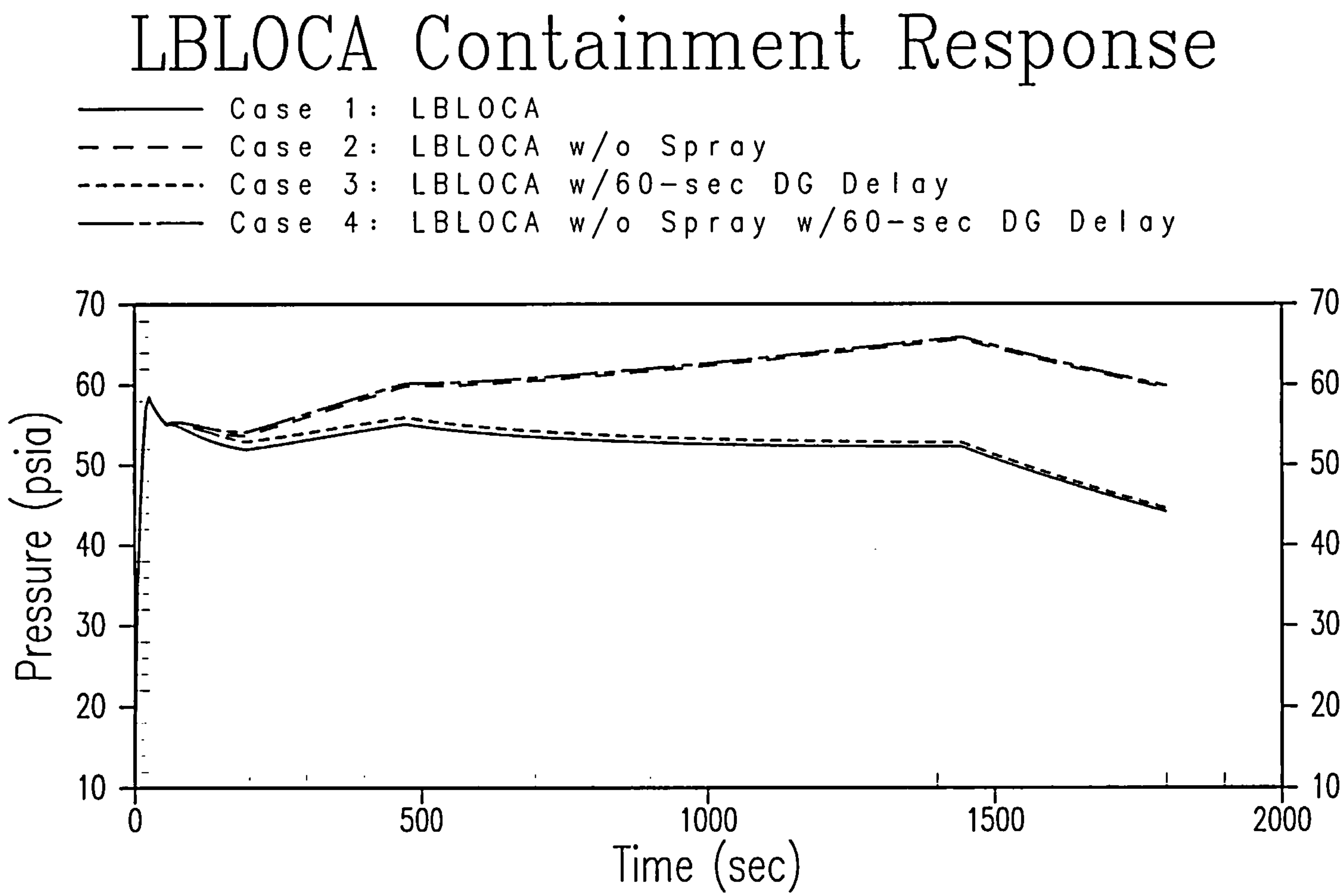


Figure 9: Large Break LOCA Pressure Response

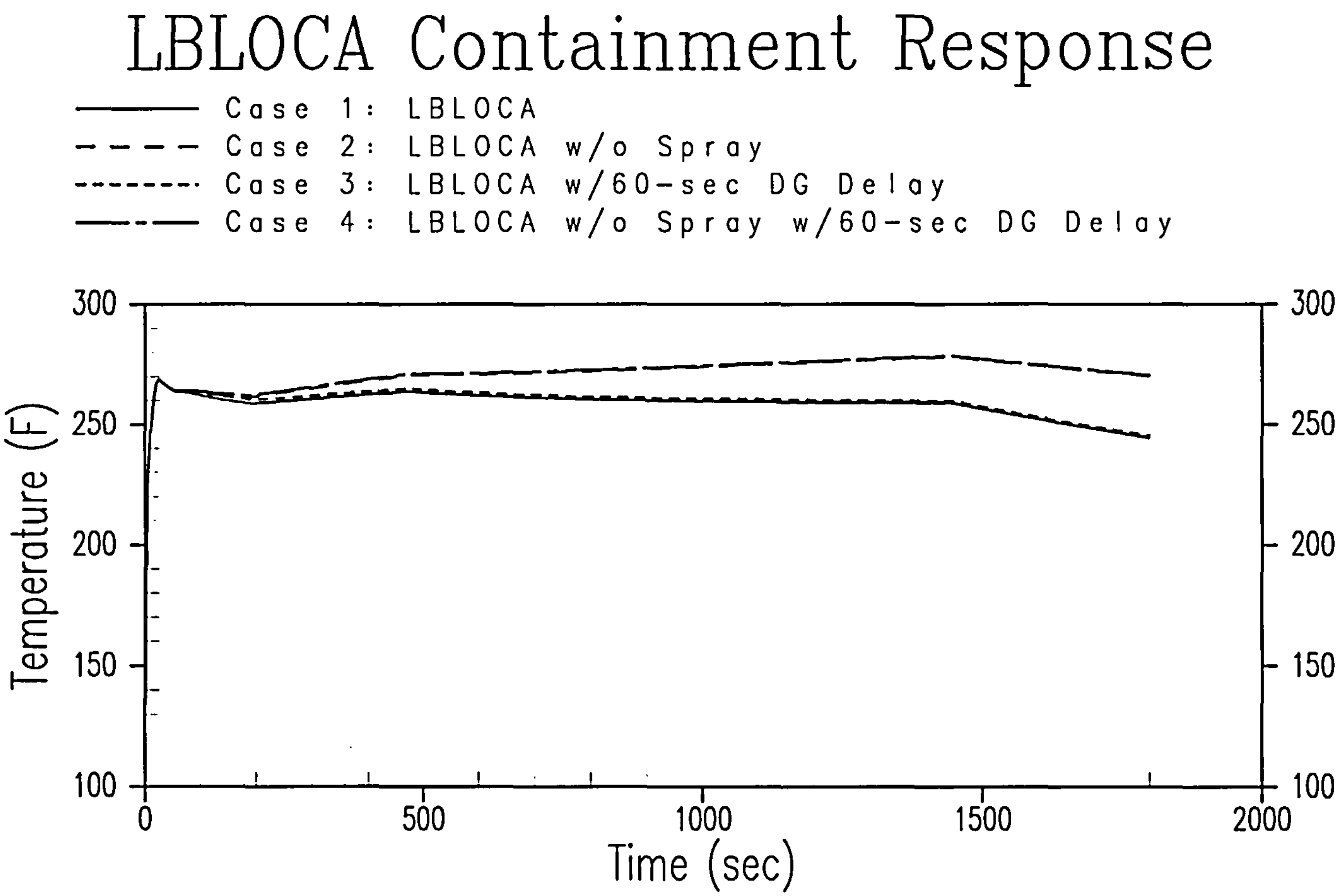


Figure 10: Large Break LOCA Steam Temperature Response

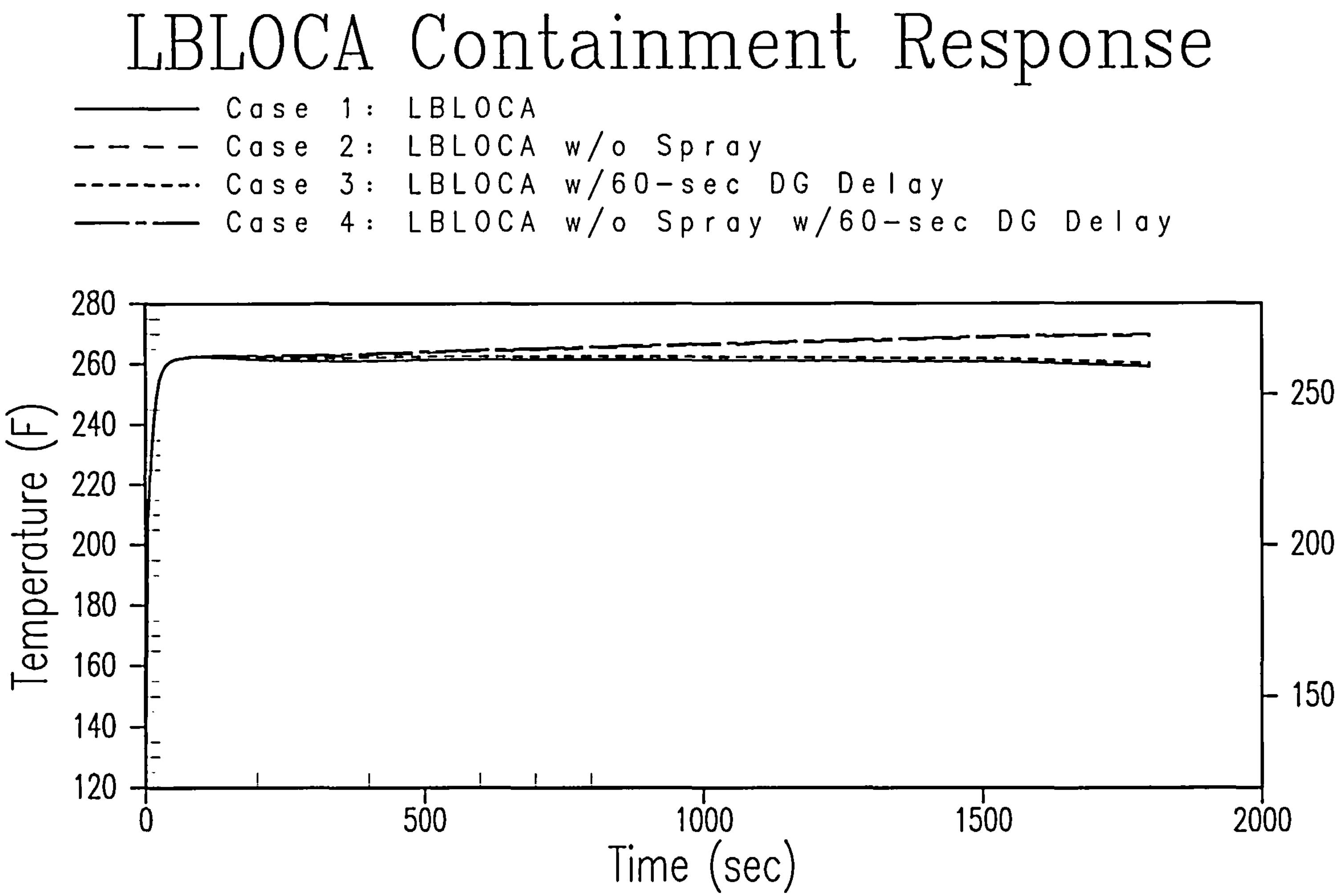


Figure 11: Large Break LOCA Sump Temperature Response

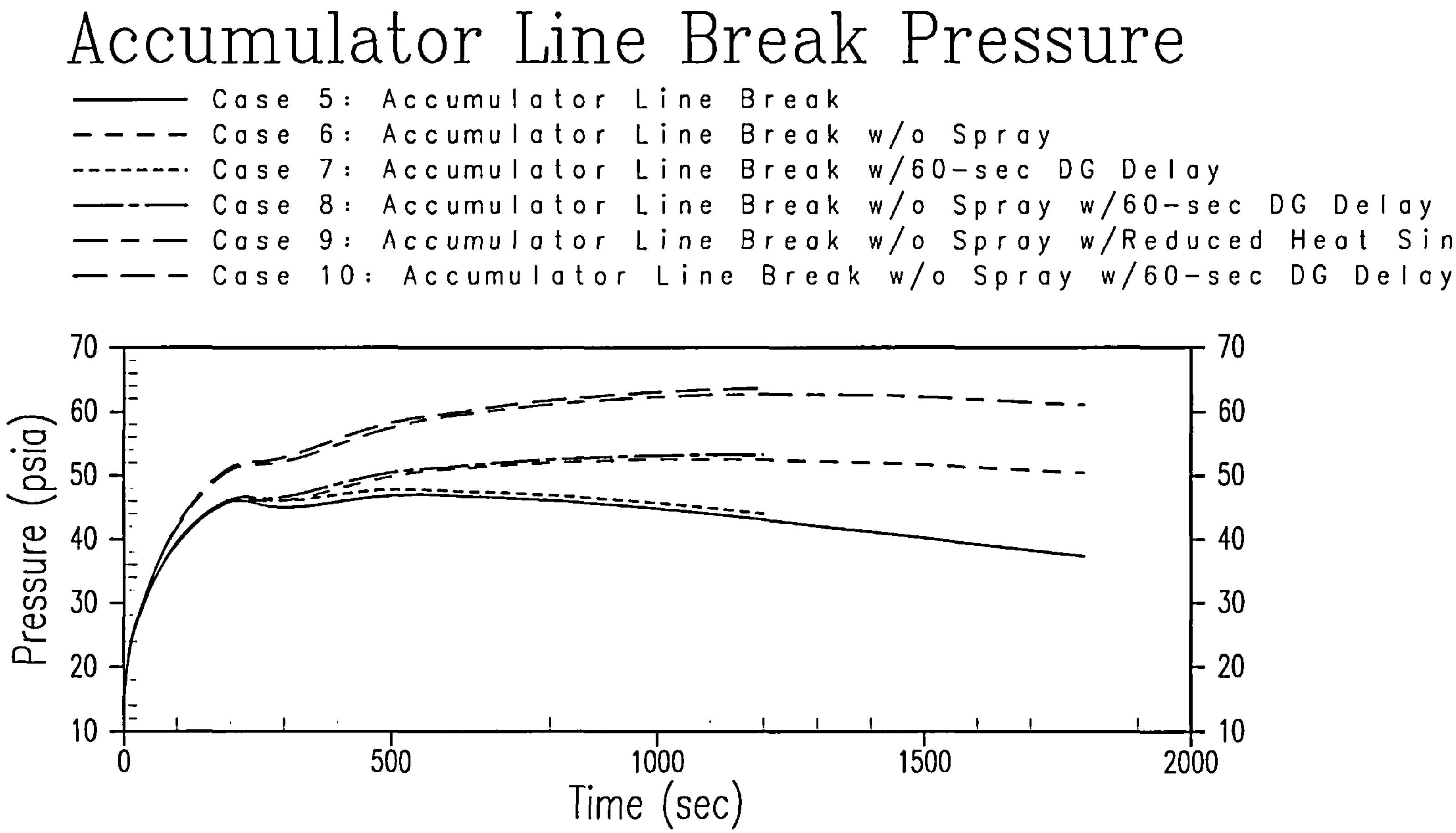


Figure 12: Accumulator Line Break Pressure Response

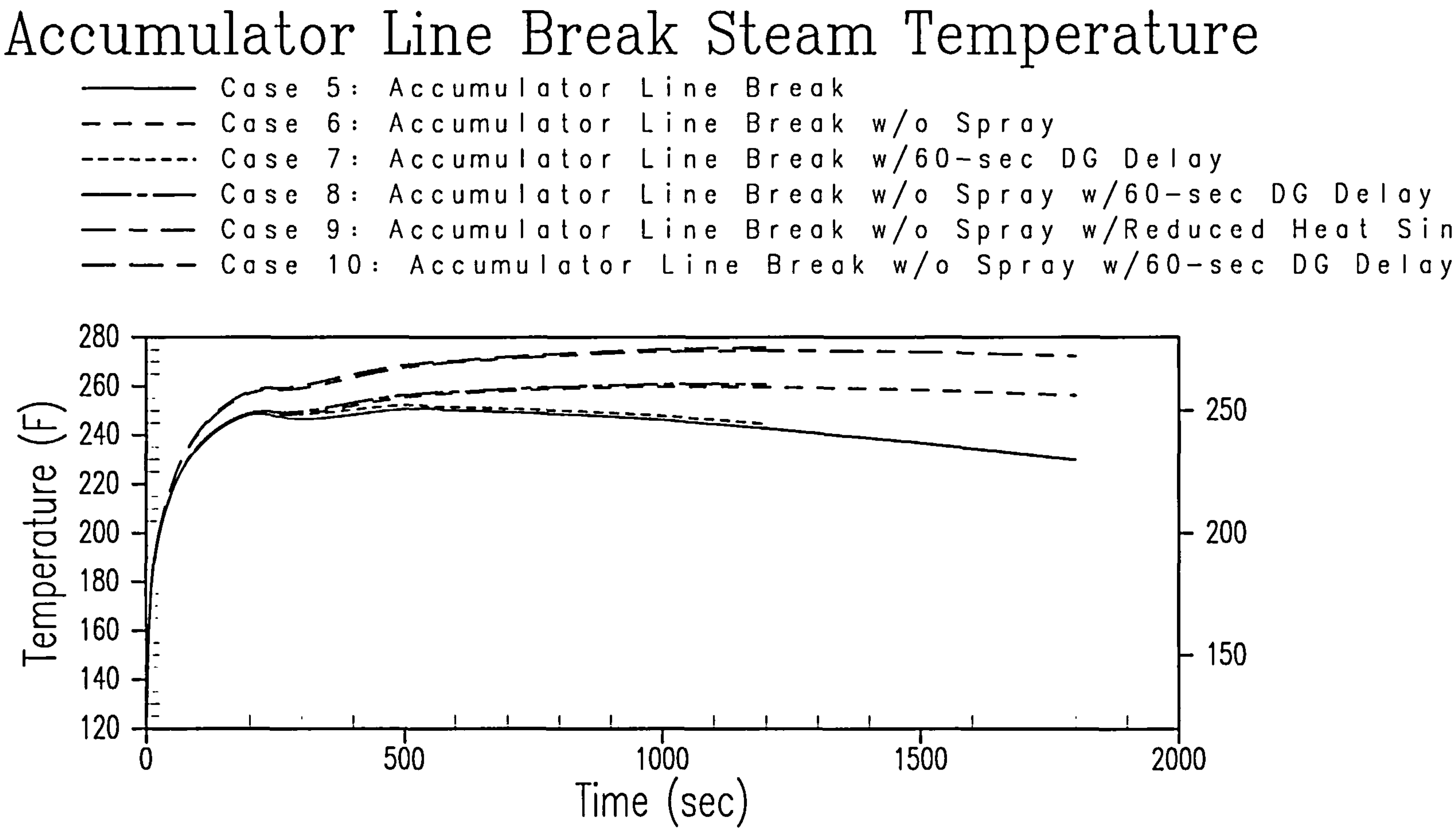


Figure 13: Accumulator Line Break Steam Temperature Response

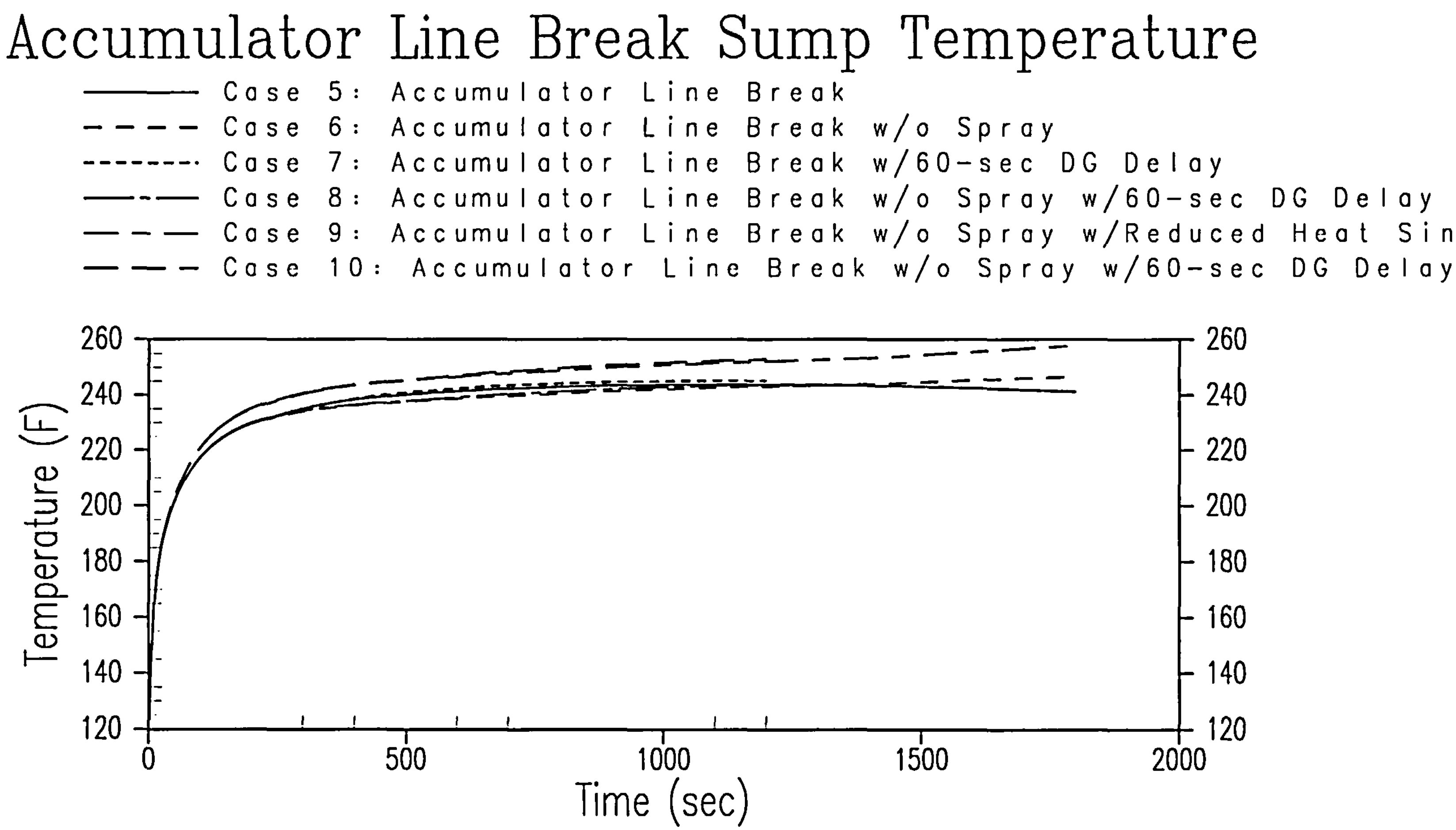


Figure 14: Accumulator Line Break Sump Temperature Response

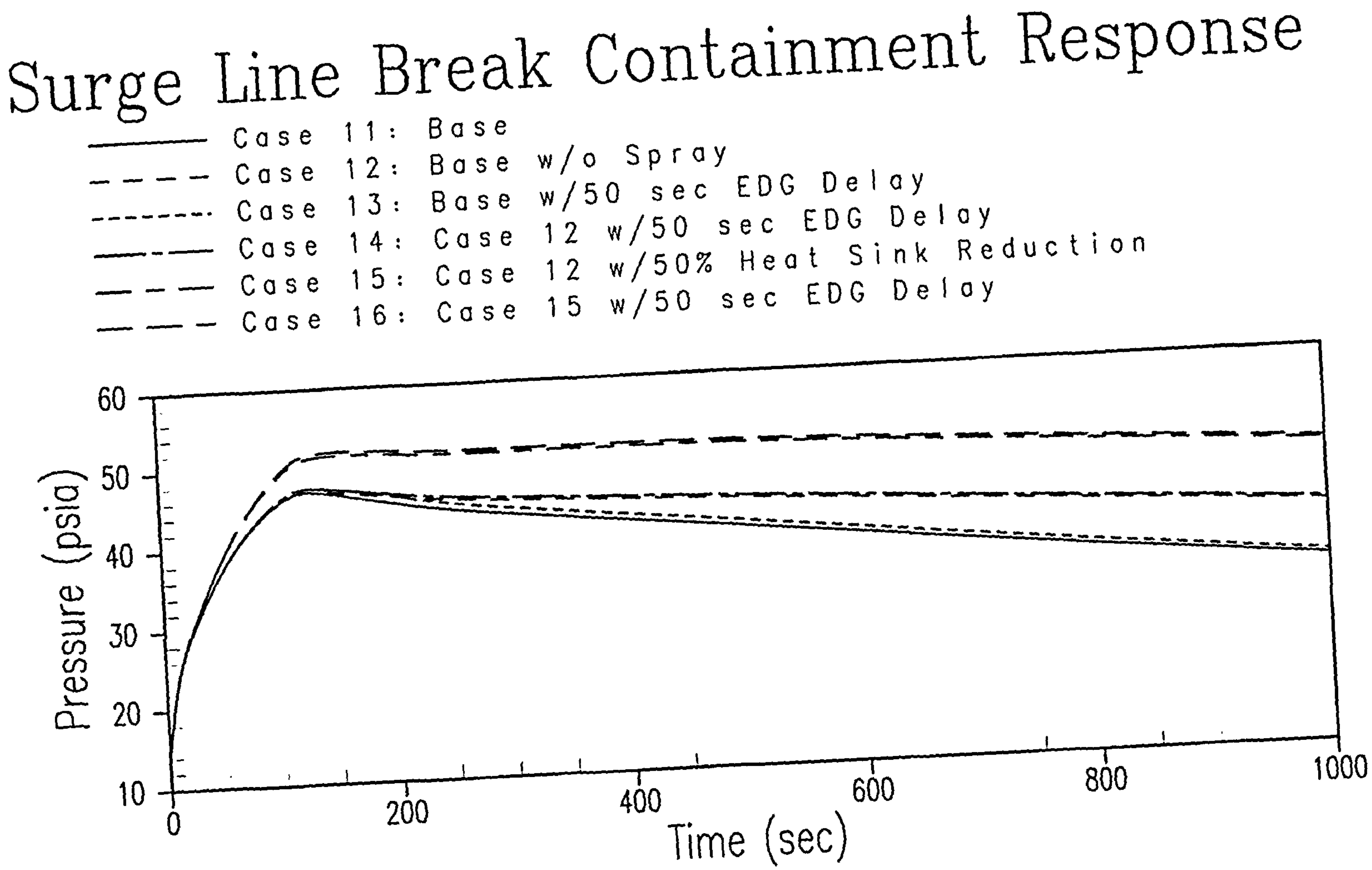


Figure 15: Surge Line Break Pressure Response

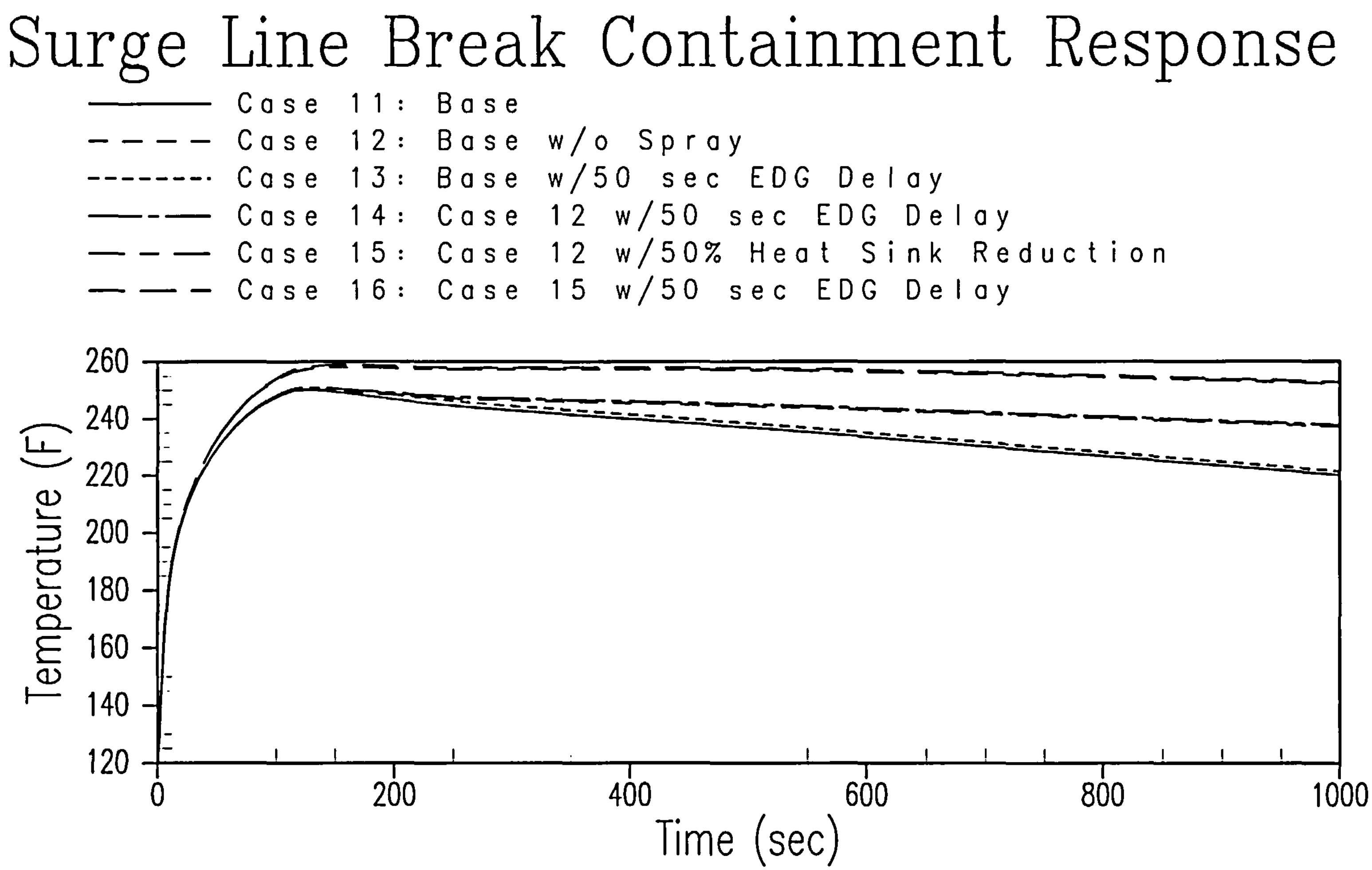


Figure 16: Surge Line Break Steam Temperature Response

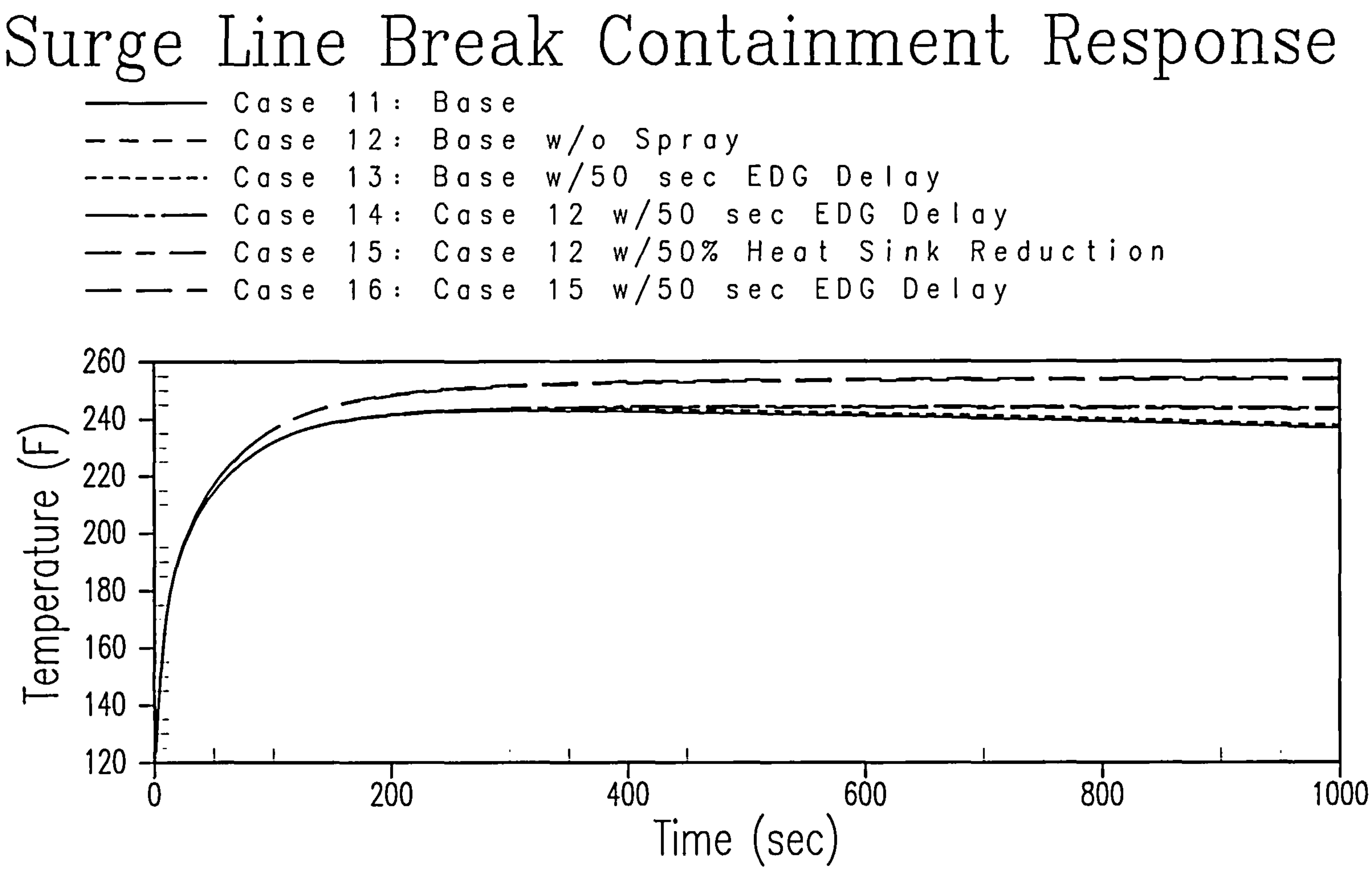


Figure 17: Surge Line Break Sump Temperature Response