AUG 14 1989

Dr. Jean-Pierre Sursock
Program Manager
Nuclear Power Division
Electric Power Research Institute
3412 Hillview Avenue
P.O. Box 10412
Palo Alto, CA 94303

Dear Dr. Sursock:

Enclosed for your information is a draft report NUREG/CR-5432, "Scoping Study of the Potential Impacts of Inadvertent Fire Suppression System Actuations in Commercial Nuclear Power Plants", August 1989, prepared for us by Sandia National Laboratories.

If, after review of this draft report, you have any comments, we will welcome them.

Consistent with our informal understanding on exchange of information in this area, we are looking forward to receiving from you a copy of your contractor's draft and final reports on the effects of fire suppressants on equipment and to discussing with you their findings.

Sincerely,

/S/

Demetrios L. Basdekas
Reactor and Plant Safety Issues Branch
Division of Safety Issue Resolution
Office of Nuclear Regulatory Research

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SCOPING STUDY OF THE POTENTIAL IMPACTS OF INADVERTENT FIRE SUPPRESSION SYSTEM ACTUATIONS IN COMMERCIAL NUCLEAR POWER PLANTS

DRAFT
FOR REVIEW AND COMMENT

DRAFT
FOR REVIEW AND COMMENT

J. C. Romig
M. P. Bohn
V. F. Nicolette
J. A. Lambright

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Sandia National Laboratories
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ABSTRACT

Fire suppression systems in nuclear power plants have experienced actuations of their fire suppression systems under conditions for which they were not intended to actuate. These inadvertent actuations have often damaged nearby plant equipment. The goal of this study was to review the past occurrences of such events and their impact on plant safety systems, and to perform a scoping analysis of the potential risk impacts of such events on plant safety.

From the review of past events, it was found that the frequency of such actuations is on the order of 0.12 events per reactor year. It was also found that 53% of such events damaged related plant equipment. Further, it was found that water systems are most likely to cause equipment damage in inadvertant actuations, with CO_2 being the second leading cause. Finally, a wide variety of important plant safety and support systems were found to have been affected.

Ten different scenarios leading to inadvertent actuation of fire protection systems due to a variety of causes were identified. A scoping quantification of these ten scenarios was performed on a prototypical PWR. The results of this quantification showed that some scenarios could result in core damage frequency incremental increases on the order of 10^{-5} to 10^{-4} per reactor year, and dose increments of 58 to 821 man-REM/year could result depending on the assumptions made. A cost/benefit analysis was performed which showed that possible modifications to prevent such inadvertent actuations would be cost-effective from a risk-averted viewpoint.

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EXECUTIVE SUMMARY

In recent years, fire suppression systems in nuclear power plants have actuated at times and under conditions for which they were not intended to actuate, often affecting and even damaging adjacent plant equipment. To quantify this issue, a scoping study was performed which involved, (a) a review of pertinent Licensee Event Reports and (b) a scoping quantification of such potential scenarios at a prototypical commercial nuclear power plant.

In the first part, over 200 Licensee Event Reports were reviewed to obtain data on the circumstances of recent inadvertent actuations. This review found that 75 inadvertent FSS actuations occurred between April 1980 and June 1988. The resulting frequency of inadvertent FSS actuations is about 0.12 events per reactor-year. For those seven events which resulted in the actuation of multiple suppression systems, it was difficult to identify a recurring cause. The causes of most of the 75 actuations were errors by plant personnel. It is significant that 53% of the inadvertent actuations damaged or in some other way affected the operation of other plant systems. Indeed, thirteen of the inadvertent actuations--17% of the total--affected other plant systems to the extent that a reactor transient resulted. The most common failure mode of the affected equipment, especially of the safety related equipment, was electrical shorting caused by FSS water reaching inadequately protected components.

In the scoping quantification portion of the study, ten different causal mechanisms were identified which could result in inadvertent fire suppression system actuations. A set of criteria were developed for identifying such accident scenarios leading to core damage. These criteria can be applied to a PRA vital area analysis for any particular plant in question to identify those accident sequences and cutsets which would lead to core damage (assuming the inadvertent FSS actuation damages critical equipment in the fire area affected).

Finally, the criteria developed were applied to a prototypical commercial pressurized water reactor. Inasmuch as these scenarios are plant-specific in regard to plant layout and types of fire suppression systems present, it was necessary to select an actual plant for the quantification of the scenarios. The Surry commercial nuclear power plant layout and fire suppression systems configuration were used because a detailed Fire PRA and supporting analyses were available as part of the NRC-sponsored NUREG 1150 program. However, no plant-specific data analysis was performed, and no detailed analysis of the propagation of smoke within each room was performed to take into account the actual location of critical equipment, and no plant-specific evaluation of the number and type of fire barriers in each zone was made. All of these factors significantly affect the quantitative results. Hence, the results presented here should be viewed as being "reasonable" but not applicable directly to the Surry plant.

For each accident sequence identified, values for the various parameters involved were chosen, and an estimate of the potential impact to core damage and risk to inadvertent FSS actuation was made. Although effort was made to use data-based estimates from existing data bases where available, simplifying assumptions on the conservative side were required in noted areas due to lack of data and in order to maintain schedules and funding constraints.

Using the complete set of accident sequences developed in the NUREG 1150 fire analysis for Surry, a full set of scenarios based on inadvertent fire suppression system activations were analyzed. The results showed that certain scenarios could lead to increases in core damage frequency in the 10^{-5} to 10^{-4} per year range. These increases were shown to represent increments of offsite dose of 58 to 821 man-REM/year depending on the assumptions made. Using estimates of costs of retrofits, simple cost/benefit measures were calculated which tended to indicate that the various plant modifications proposed would be cost-effective from a risk-averted viewpoint.

1.0 INTRODUCTION

In recent years, fire suppression systems (FSS) in nuclear power plants have actuated at times and under conditions for which they were not intended to actuate. Since these fire suppression systems (FSS) are located near the critical equipment they are designed to protect, these inadvertent actuations have often affected and even caused damage to adjacent plant equipment. On some occasions, the damage has been to safety related equipment, that is, equipment required to ensure the capability to safely shut down the plant. On other occasions, the damage has been to equipment required for the normal operation of the plant, and, therefore, the reactor has had to be shut down. As a consequence, the inadvertent actuation of fire suppression systems represents a potentially important safety issue requiring further study.

In the recently completed Fire Risk Scoping Study [1], the inadvertent actuation of fire suppression systems in commercial U.S. nuclear power plants was briefly reviewed. Seventy-one events resulting in submission of a licensee Event Report (LER) were identified during the period from 4/1/80 to 7/14/87. The average frequency of occurrence of these inadvertent actuation events was found to be approximately 10 per year.

The Fire Risk Scoping Study was limited in scope and did not attempt to quantify the attendant contribution to core damage frequency (CDF) resulting from the inadvertent actuation of FSSs, primarily because the impact of inadvertent suppression system actuations was found to be very plant specific. However, it was concluded that such events could significantly impact the risk at a specific plant only if multiple safety systems could be affected by the inadvertent suppressions system actuation event.

In this work the potential safety significance of single and multiple inadvertent FSS actuations is assessed. This includes a more complete review of operational experiences involving such inadvertent FSS actuation, and a quantitative assessment of the attendant contribution to core damage frequency (CDF) for a prototypical PWR plant.

There are four main potential causes of inadvertent actuation of fire suppression systems, as shown on Table 1. For the general cases of Random and Seismic-Induced actuations, several potential root causes are also shown.

Table 1

Potential Causes of Inadvertent FSS Actuation

A. Random causes

Human Error

Steam Pipe Break

Break of FSS Itself

B. Actuation induced by fire in adjacent area and smoke spread

C. Seismic

Dust actuating smoke detectors

Failure of FSS (e.g., failure of wet pipes, sprinkler heads, anchorage of CO_2 tanks, etc.)

Actuation caused by relay chatter

D. Fire external to plant (smoke via ventilation system)

The objective of this study was to provide a probabilistic basis on which to evaluate the potential affect on core damage frequency and risk due to spurious suppression system actuations. This objective was accomplished by first reviewing a comprehensive listing of events involving inadvertent fire suppression system actuations. The inadvertent actuations were then categorized in order to draw some useful conclusions about the causes and effects of these actuations. Finally, a scoping quantification of the potential impacts of such events was performed both in terms of incremental increase in core damage frequency and in terms of incremental increase in risk for the scenarios identified. Finally, a simple cost/benefit analysis was performed.

2.0 REVIEW OF FIRE SUPPRESSION SYSTEM ACTUATION EVENTS

An evaluation of past inadvertent FSS actuations for generic insights was performed. This review was conducted with the following goals in mind:

a) Identify which events were accounted for in the Fire Risk Scoping Study, and which events are different.

b) Determine which types of FSSs were involved in the events.

c) Categorize common cause initiators resulting in FSS actuation.

d) Identify when redundant trains of safety equipment were affected.

e) Determine how plant layout influenced the event.

f) Identify which events resulted in multiple FSS actuations.

g) Identify which events resulted in or were caused by a plant transient or a fire in another location inside the plant.

h) Identify specific equipment which is vulnerable to inadvertent FSS actuations.

i) Identify any human interactions data showing an effect on operator performance resulting from FSS actuations.

2.1 Review Procedure

The primary source of information for this study was a search of the Licensee Event Report (LER) data base which resulted in a list of 127 abstracts involving the actuation or operation of fire suppression systems at nuclear power plants. The original LERs were submitted to the Nuclear Regulatory Commission (NRC) by individual nuclear power plants in the United States to report events that affected the safe operation of the plant. Since an LER is required only if safe plant operation is actually or potentially affected, it is possible that non-safety related inadvertent actuations were not reported. The listed events occurred during the period from April 1980 through June 1988.

One other source [1] provided information on one event that involved the inadvertent actuation of a fire suppression system. The additional event was an inadvertent deluge actuation at the Hatch plant in November of 1982.

An additional source reviewed was a list of LERs dealing with actual fires. These were examined in order to verify that the reported fire events did not result in inadvertent actuation of additional suppression systems beyond those required by the fire event. This list of actual fire events consisted of 108 LER's for events occurring between February 1980 and June 1988 obtained from the Oak Ridge National Laboratory LER data base. From this review of actual fire events, no such inadvertent actuations were found.

To categorize the inadvertent actuations, the list of inadvertent actuation events was reviewed with certain questions in mind. The major question was what, if any, safety-related frontline or support systems were affected by the actuation. This question was further broken down into identifying the specific equipment affected, and the failure mode of that equipment. Another item of interest was whether the actuation was related to a plant transient, either immediately before or after the actuation. Other items of interest were the cause of the actuation, the FSS component that initiated the actuation, and how many suppression systems actuated. In addition, the date of the incident, the type of nuclear plant involved, and the power level at the time of the incident were noted. To assist in the review, these questions were arranged into the checklist shown in Figure 1. Sheets summarizing each event reviewed are included as Appendix A.

The LER abstracts varied greatly in the amount of detail they provided. Some abstracts included great detail about the cause of the inadvertent actuation and the failure mode of the affected systems. On the other hand, others stated only that a suppression system had actuated, without describing the possible cause of the actuation. For this reason, many of the actuations are categorized as having an unknown cause.

2.2 Results of Review of Events

After reviewing the list of possible events, it was determined that 75 of the events fit the definition of an inadvertent actuation of a fire suppression system, namely, the actuation of a fire suppression system in a room without the presence of a fire requiring the suppression system. Most of these events involved the application of the fire suppression agent in the designed manner, i. e., from the sprinkler head or from the Halon nozzles, but at the wrong time. Some of these events involved the leaking of a suppression system. For example, water leaking from a deluge valve or pipe was relatively common. Fifty-two events from the original list of 127 were excluded from consideration as an inadvertent actuation. Typical reasons for excluding an event were that the event did not actuate the release of the fire suppression agent or that the FSS component that initiated actuation failed during a test of that specific component.

This total number of events can be compared to the total number of reactor years to obtain a frequency of occurrence for inadvertent actuations. Information on the number of nuclear power plant reactor years is available from the Sandia fire data base [2]. Between September 30, 1980 and June 3, 1988, the number of reactor years in the United States (including shutdown periods) was about 640. (The shutdown

Figure 1. Sample Checklist

Inadvertent Actuation of Fire Suppression System Checklist

Plant: Type:

Date of incident:

1. % power/mode?

2. Initiator?

3. How many fire suppression systems actuated?

4. Suppression system(s) involved?

5. Component(s) of fire suppression system which failed/initiated actuation?

6. Affected area(s) of plant?

7. Affected plant system(s)?

8. Affected equipment?

9. Failure mode?

10. Result in a plant transient?

11. Result of a plant transient?

12. Result of a fire elsewhere?

times are included because several of the inadvertent actuations occurred during refueling or other shutdown periods.) Since 74 inadvertent actuations occurred during this time period, the relative frequency of occurrence is approximately 0.12 inadvertent actuations per reactor year.

The events can be subdivided according to the year of occurrence. With this grouping, the histogram shown in Figure 2 is obtained. Note that the totals for 1980 and 1988 are only for part of that year, and hence, are incomplete since the data base did not completely cover those years. As can be seen, the number of reported actuations peaked at 15 during the year 1982. The fewest number of events, 5, occurred during 1984. If the incomplete data for 1980 and 1988 is omitted, the average number of inadvertent actuations in a year is calculated to be about 10.3.

The events can be further classified according to the type of plant at which they occurred. Of the total of 75 events, 30 occurred at Boiling Water Reactors (BWRs) and 45 occurred at Pressurized Water Reactors (PWRs). Using the Sandia fire data base, one can determine the frequency of occurrence for the different types of reactors. The resulting number of inadvertent actuations per reactor year is about 0.14 for BWRs and 0.11 for PWRs.

A significant number of the inadvertent actuations happened during normal power operations. Although the power level was not given for 25 of the events, 22 of the events occurred at reported power levels of 80% or higher. Another 22 of the events occurred during refueling, reactor startup, or other low power operations, while the remainder occurred at intermediate power levels. Clearly, an inadvertent FSS actuation can occur at any time.

When the inadvertent actuations are classified according to the type of suppression system that actuated, it is seen that the majority of the actuations occurred to water-based systems. In 46 cases, the actuating system was a water deluge system. An additional 17 reports listed the actuation of other types of water-based systems, for a total of 63 events being the actuation of a water-based system. A carbon dioxide (CO_2) system actuated in 9 of the events, and a Halon system actuated in 9 events also. No attempt was made to determine the relative frequency of actuation on a per-system-year basis for the different types of suppression systems. (This would require a detailed survey of all plants to determine the number of operating years for each type of fire suppression system). However, one previous study [3] found that high pressure CO_2 systems actuated most often on a per-system-year basis. (The number of high pressure CO_2 actuations had a relatively high frequency because there are typically less automatic CO_2 systems than deluge systems installed in any given nuclear power plant). In general, it would provide a better picture of the risk due to inadvertent actuations if such system specific occurrence frequencies were available.

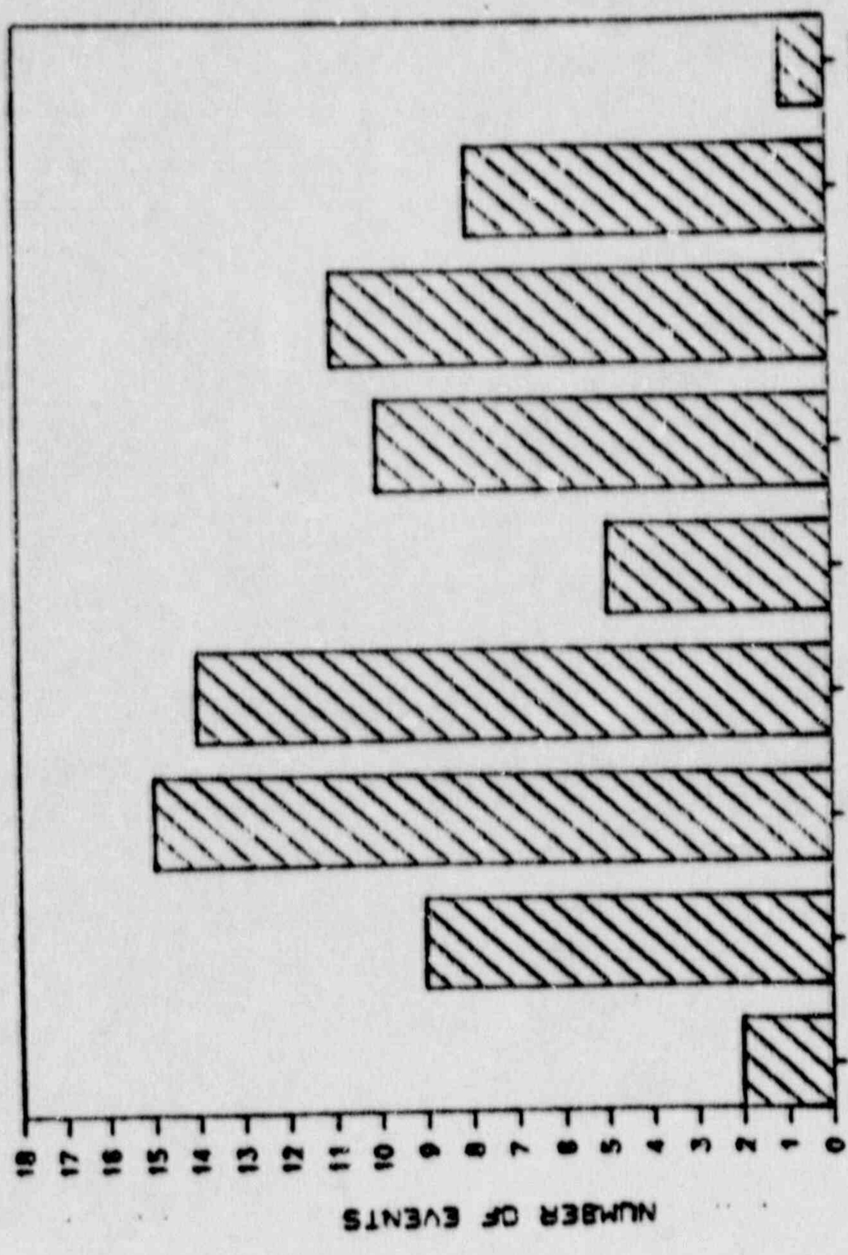


Figure 2. Inadve tent Actuations by Calender Year

The numbers above total to more than 75 because some of the events led to the actuation of more than one suppression system. Specifically, four of the events, all at Three Mile Island, were the actuation of a deluge system and a Halon system in the Air Intake Tunnel at the same time. (The causes were lightning twice, welding, and an unknown cause.) During one event at Surry in December of 1986, all three types of systems were actuated after a feedwater pipe broke--the sprinklers first, and then the CO_2 and Halon systems. In addition, there were two cases in which the deluge systems in several different plant areas were actuated simultaneously. (The causes were personnel error during a control panel test and an unknown cause.)

When the inadvertent actuations are analyzed for an initiating cause, the most common initiator is found to be human error. In 20 cases, the cause was simply personnel error: not following proper procedures, miscommunication, bumping switches, or other mistakes. In this report, this type of error is distinguished from the more subtle error of a mistake in or omission from a documented test or maintenance procedure. This latter type of error resulted in 11 actuations during the performance of a test or maintenance procedure. Steam, dust, and high humidity levels reportedly caused 8 of the inadvertent actuations, although the detector sensitivity certainly contributed to these actuations. In 7 cases, leaking deluge system pipes and valves damaged other equipment and are therefore counted as inadvertent actuations. Three actuations were caused by pressure spikes in the air or water system. Two inadvertent actuations were the result of improperly conducted welding activity. Lightning was blamed for two of the actuations. Wet fire detectors also caused two actuations, as did failed suppression system relays. Smoke from a heater caused one actuation, and other equipment failures caused 4 actuations. The initiating cause was unknown or not reported for 13 of the 75 inadvertent actuations. These causes are shown in the bar graph in Figure 3.

In addition to the initiating cause, each actuation was also characterized by the fire suppression system component that initiated the actuation. For example, if plant personnel inadvertently shorted the FSS control circuitry during a maintenance activity, the initiating cause would be personnel error and the initiating component would be the suppression system control circuits. The totals are shown in Figure 4. In 22 cases, the valves in the FSS were the initiating component. In another 19 of the events, a fire detector actuated the suppression system. A problem with the FSS control circuitry initiated 5 of the actuations. In 4 cases, the suppression system actuation switch was the initiating component. Three times an FSS pipe broke or leaked, and three times problems with the air pressure regulator used by the suppression system started the actuation. Once, the failure of an air compressor used by a deluge system initiated an event. For 18 of the inadvertent actuations, the initiating component was unknown or not reported.

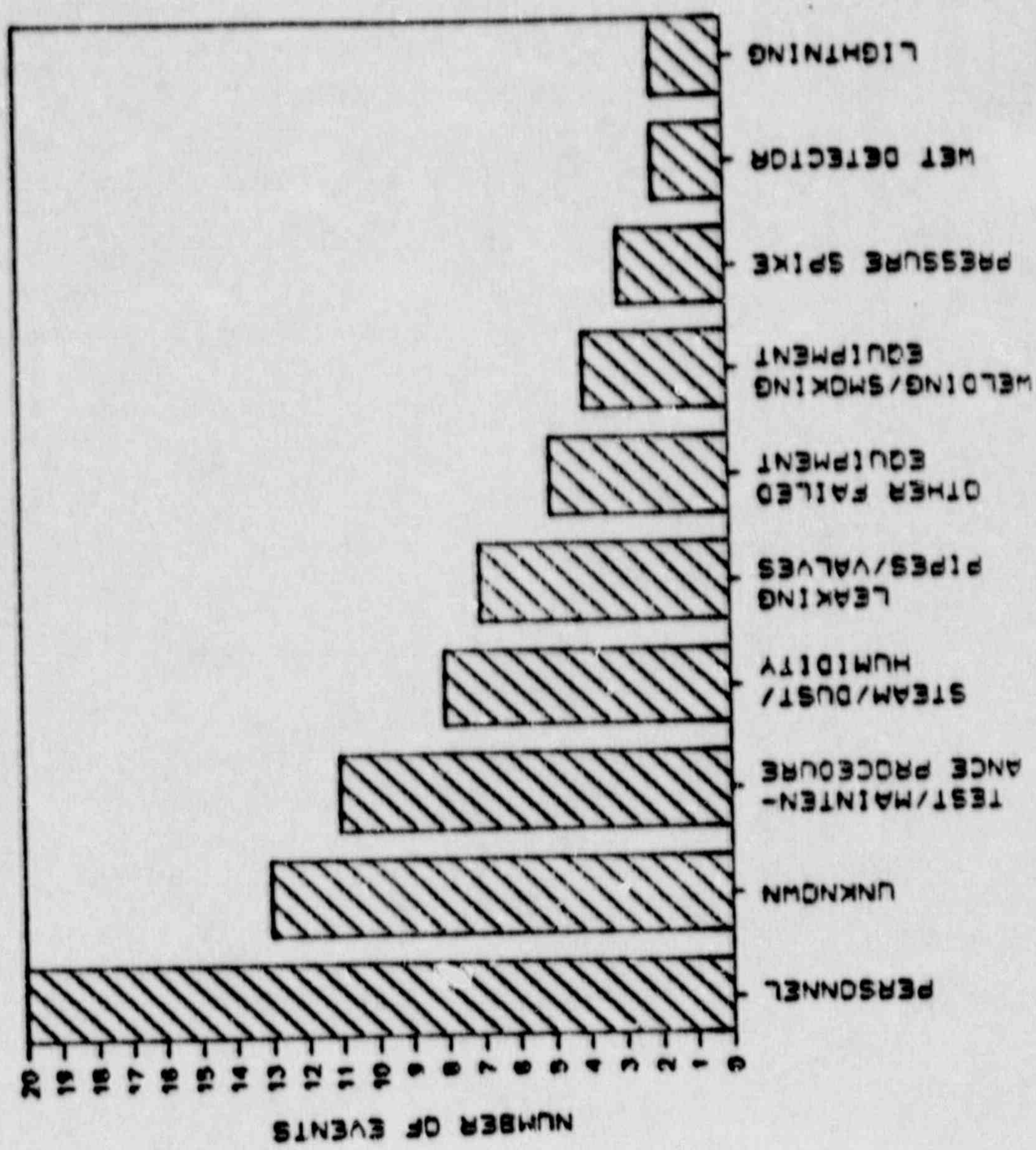


Figure 3. Causes of Inadvertent Actuations

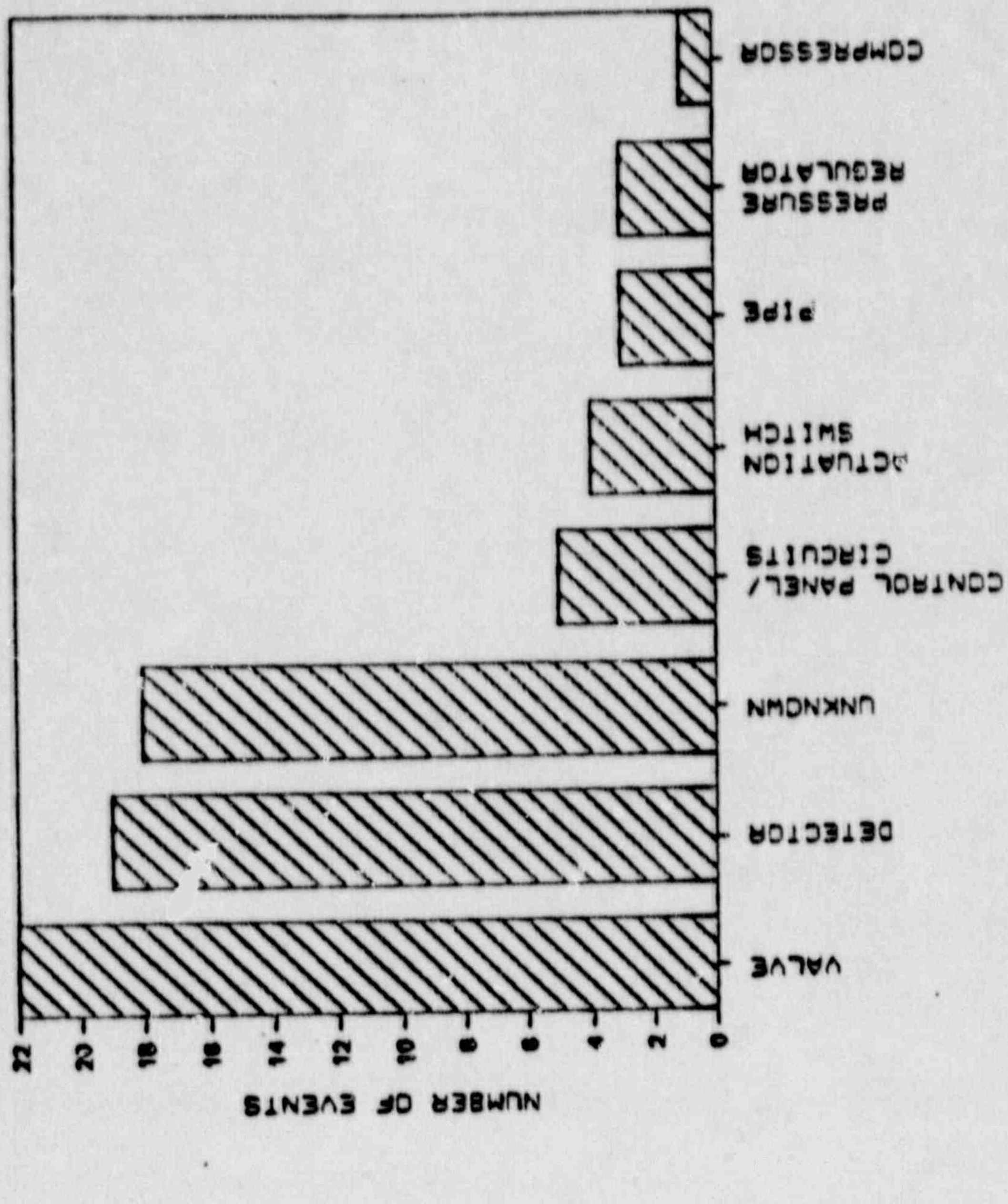


Figure 4. Initiating Components of Inadvertent Actuations

The initiation of three of the inadvertent actuations occurred while a reactor or turbine trip was in process. In all three cases, an equipment problem during the course of the trip allowed steam to escape. This escaping steam then actuated a nearby fire suppression system. Included here is the event at Surry in December 1986, where, during a reactor and turbine trip a feedwater pipe broke, releasing steam in the plant turbine building. The hot steam then actuated over 60 sprinkler heads in the building.

A significant result of this review is the finding that more than 40 of the 75 inadvertent actuations damaged or impaired some other system in the plant. Thus, if damage to SBGT charcoal filters is included, 53% of the events resulted in damage to plant systems. The most commonly affected safety system, as shown in Table 2, was the electric power system. In 8 cases, an inadvertent actuation caused the loss of power to some of the plant electrical busses. For example, an inadvertent deluge actuation at Palisades in 1987 resulted in the loss of all offsite power, thereby forcing an automatic reactor trip. The second most commonly affected system was the plant ventilation. Examples here include two cases in which the release of carbon dioxide contaminated the air in an entire building. The third most commonly affected system was the Standby Gas Treatment System (SBGT). In several instances, leaking deluge valves saturated the charcoal filters in the SBGT. Four actuations rendered the High Pressure Coolant Injection System (HPCI) inoperable, and four inadvertent actuations caused damage to other fire suppression system components. As can be seen from the table, other affected systems included the Core Spray System, the Reactor Protection System (RPS), the diesel generators, the Reactor Coolant System (RCS), and the Control Rod Drives (CRD). Clearly, inadvertent actuations of fire suppression systems have affected a variety of important plant safety systems.

Within each of these affected systems, the particular equipment that suffered damage was identified. The piece of equipment that was damaged most often was a charcoal filter/charcoal bed. Usually, the saturation of the charcoal filters by deluge water made the filters inoperable necessitating their replacement. As Table 3 shows, charcoal filters/beds were damaged 13 times. More serious damage occurred during 7 events when electrical control panels were shorted by the suppression system. These shorted panels controlled such systems as the Rector Coolant System, the HPCI, and the CRD. In four events a power transformer was shorted out by water from the suppression system, and in four other events a power transformer was inadvertently tripped off-line as a result of the suppression system actuation. Other affected equipment included pumps, the plant computer, and an RPS motor generator set.

In conjunction with the analysis of the affected plant equipment, the particular failure mode of that equipment was also determined. The

Table 2

Systems Affected By Inadvertent
Fire Suppression System Actuations

Affected system	Occurrences
Electric power	8
Ventilation	7
Standby gas treatment system	5
HPCI	4
Other fire protection systems	4
Core spray system	2
Steam line valves	2
Diesel generator	2
Reactor pressurizer	1
Reactor protection system	1
Reactor coolant system	1
Plant computer	1
Control rod drive	1
Main turbine	1
Emergency equipment cooling	1
Hydrogen recombiner	1
Feedwater pump	1
Instrument air system	1
Communications	1
Access control	1
Emergency air cleanup system	1
Emergency air supply system	1
Standby filter unit	1

Note: For 35 events, no system was reported affected

Table 3

Equipment Affected By Inadvertent Fire Suppression System Actuations

Affected Equipment (with failure mode)	Occurrences
Charcoal filters/beds (wetting of charcoal)	13
Control panels (water induced short)	7
Transformers (water induced short)	4
Transformers (FSS induced trip signal)	4
Sensors/detectors (water induced short)	4
Pumps (water induced short)	2
Air supply (CO_2 or halon contamination)	2
Plant computer (FSS induced trip signal)	1
Motor generator set (water induced short)	1
Load centers (water induced short)	1
Instrument air system (water contamination)	1
HPCI oil (water contamination)	1
Diesel exhaust damper valve (water contamination)	1
Door access card readers (water induced short)	1
Exhaust filter (wetting of filter)	1
Radio repeater (CO_2 caused ice buildup)	1
Fire retardant barrier (water damage)	1
HPCI equipment (unspecified)	1

Note: For 35 events, no equipment was reportedly affected investigation found that the most common failure mode was electrical shorting caused by water from the suppression system. As seen from Figure 5, electrical shorting caused equipment failure during 18 of the inadvertent actuations. In 14 cases, a charcoal filter or bed was wetted to the extent that it was inoperable. The third most common failure mode was a FSS generated trip signal. For example, when the deluge inadvertently actuated over Common Service Station Transformer (CSST) D at Sequoyah in June 1986, the FSS control circuits electrically isolated both CSST C and D to preclude any transformer shorting. Although neither transformer actually failed, they were removed from service by the inadvertent actuation. This type of FSS generated trip signal isolated plant equipment during 4 of the actuations. Other failure modes were contamination, water damage to a fire retardant barrier, and impairment of electrical equipment caused by the ice generated by excessive carbon dioxide release.

The seriousness of the equipment damaged or affected is further indicated by the number of inadvertent actuations which resulted in a plant transient. Indeed, 13 of the 75 inadvertent actuations led directly to a reactor trip or plant shutdown. This number represents 17% of the total number of inadvertent actuations. The sequence of events in four of these cases was that water from an inadvertently actuated sprinkler system near the plant startup transformer either shorted or tripped off-line the transformer. The loss of this transformer then resulted in the loss of electrical power to critical busses, forcing the operators to shut down the reactor. During four other events, suppression system water entered a control panel or switchgear cabinet and shorted the electrical circuitry so that erroneous control signals were sent to critical equipment. The resulting misconfiguration forced the operators to trip the reactor. The fact that these similar chains of events happened at more than one plant points out the potential for them to recur in the future. Indeed, depending on which circuits might be shorted, it is easy to hypothesize how this last chain of events could have led to a very serious accident.

2.3 General Conclusions From Review of Events

In summary, the operating experience with nuclear power plants has shown that approximately 10 inadvertent fire suppression system actuations occur each year in the U. S. This average is based on the finding that 75 inadvertent actuations occurred between April 1980 and June 1988. When this number is compared to the number of reactors operating in the U. S., the frequency of inadvertent FSS actuations is calculated to be about 0.12 events per reactor-year.

A water-based FSS was involved in most of the inadvertent actuations--84%. During five events, more than one type of FSS actuated, and three events involved the actuation of FSS in more than one plant area. For these multiple FSS actuations, it was difficult to identify a recurring cause.

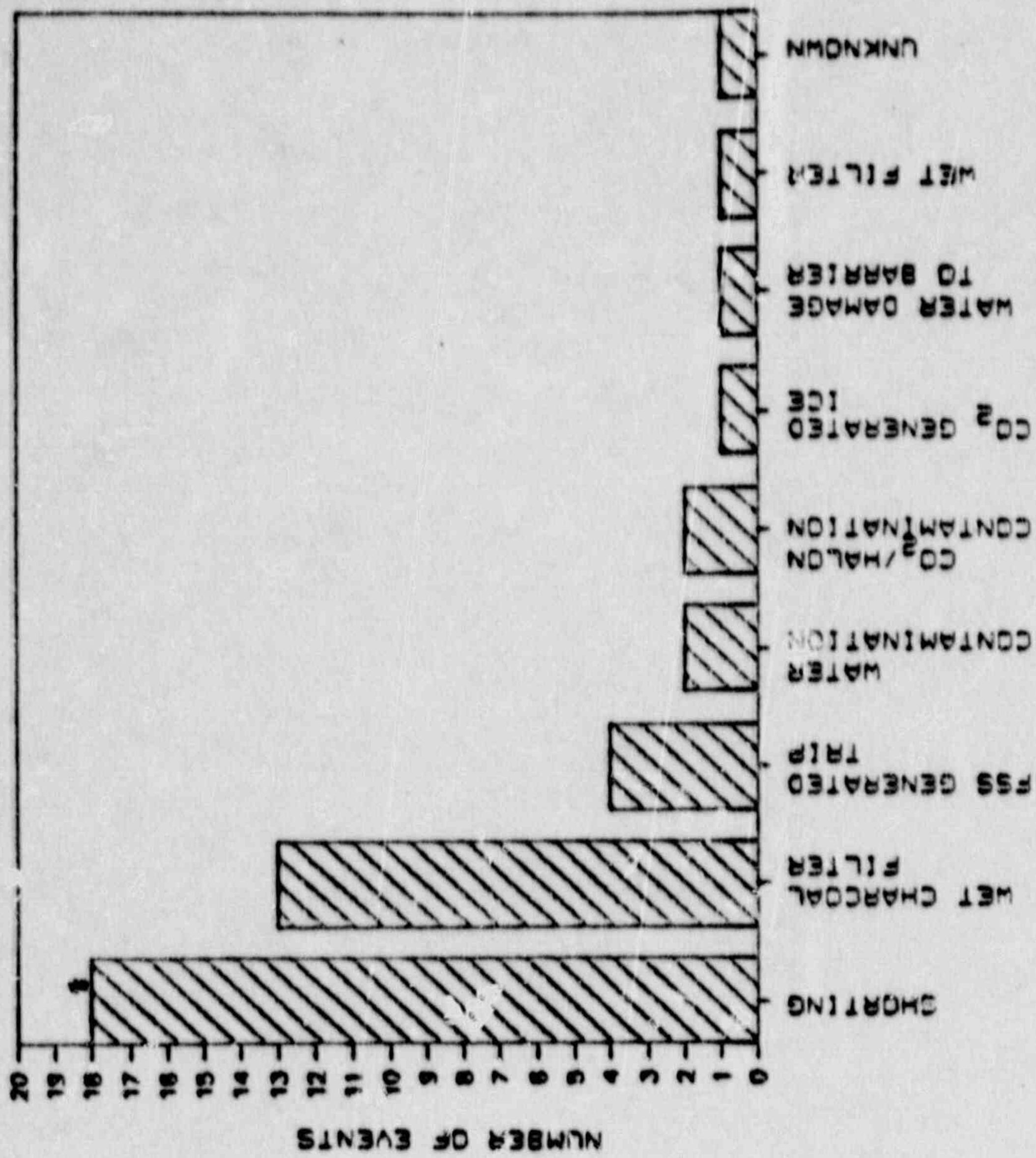


Figure 5. Failure Mode of Equipment Affected by Inadvertent Actuations

The cause of most of the actuations was human error. These errors ranged from misunderstandings by personnel, to bumping of the switches, to inaccuracies in test procedures. In all, 41% of the inadvertent actuations occurred as a result of human error. Unforeseen operating environments--steam, dust, and lightning--caused another 13% of the actuations. Actual failures of FSS components caused only 18% of the inadvertent actuations.

It is significant that 53% of the inadvertent actuations damaged or in some other way affected the operation of other plant systems. As seen on Table 2, in many cases, the affected systems were safety systems required for the safe operation or shutdown of the plant. Typical affected systems were the plant electric power, the Standby Gas Treatment system, the HPCI, the core spray system, and other fire protection systems. Thirteen of the inadvertent actuation events (17% of the total) caused a reactor transient event.

The way in which these systems were affected was by the interaction of the FSS with nearby equipment. The affected plant equipment was most often charcoal filters, control panels, transformers, and sensors. The particular failure mode of the affected equipment, especially for the safety related equipment, was most often electrical shorting caused by FSS water reaching components with inadequate insulation. Another common failure mode was contamination resulting because water, CO_2, or Halon spread to areas it was not intended to. Wetting of charcoal filters, although a common occurrence, generally did not cause a significant impact on the safe operation of the plant.

3.0 METHODOLOGY FOR EVALUATION OF POTENTIAL ACCIDENT SCENARIOS CAUSED BY INADVERTENT FSS ACTUATION.

The safety significance of inadvertent actuations of FSSs is highly plant specific, depending on such factors as the plant layout and amount and types of automatic suppression systems. Furthermore, the significance of the inadvertent actuation of any particular FSS is highly dependent on the systems inter-dependencies as determined by the logic models (event trees and fault trees) as well as potentially important random or test/maintenance unavailabilities. Thus to rigorously analyze the impact of such events, one must make use of the models and logic developed in a PRA for the plant in question. A methodology for accomplishing this was developed as part of this project. This methodology is based on use of a "vital area analysis" which is an important part of the fire probabilistic risk assessment methodology developed by Sandia National Laboratories for the US NRC. The methodology is general, and can be applied to any plant for which a detailed PRA and vital area analysis are available.

3.1 Vital Area Analysis

The basic tools of any PRA are the event trees and fault trees which describe the plant's response to any off-normal condition (initiating event) which requires the plant to be shutdown. The event tree enumerates the possible end states which result (i.e., successful shutdown, core damage, or core vulnerable) depending on the success or failure of the safety systems required to mitigate the off-normal condition.

The occurrence of a significant fire in a nuclear power plant results in a plant transient caused by the operator either manually shutting down the plant or the plant automatically tripping as a result of the fire itself. Under some circumstances, fires can occur at some plants which cause a loss of offsite power transient in which the plant is automatically scrammed. Thus, for those inadvertent actuations caused by a fire or by random failures in the FSS, a general plant transient event tree should be used to quantify the effect of inadvertent FSS actuations.

By contrast, when a seismic event occurs, the loss of offsite power (LOSP) is highly likely due to failure of ceramic insulators in the switchyard. In this case, the LOSP transient tree must be used.

As examples, Figures 6 and 7 present the general transient event tree and the LOSP transient event tree for the Surry nuclear power plant, a Westinghouse PWR (Reference 4). Each of the (non-success) branches on this tree represent a potential accident scenario. The success or failure of the required safety systems (shown across the top) is determined by fault trees, which are downward branching trees which logically identify all possible combinations of component failures (due to any cause) which lead to the failure of the safety system in question.

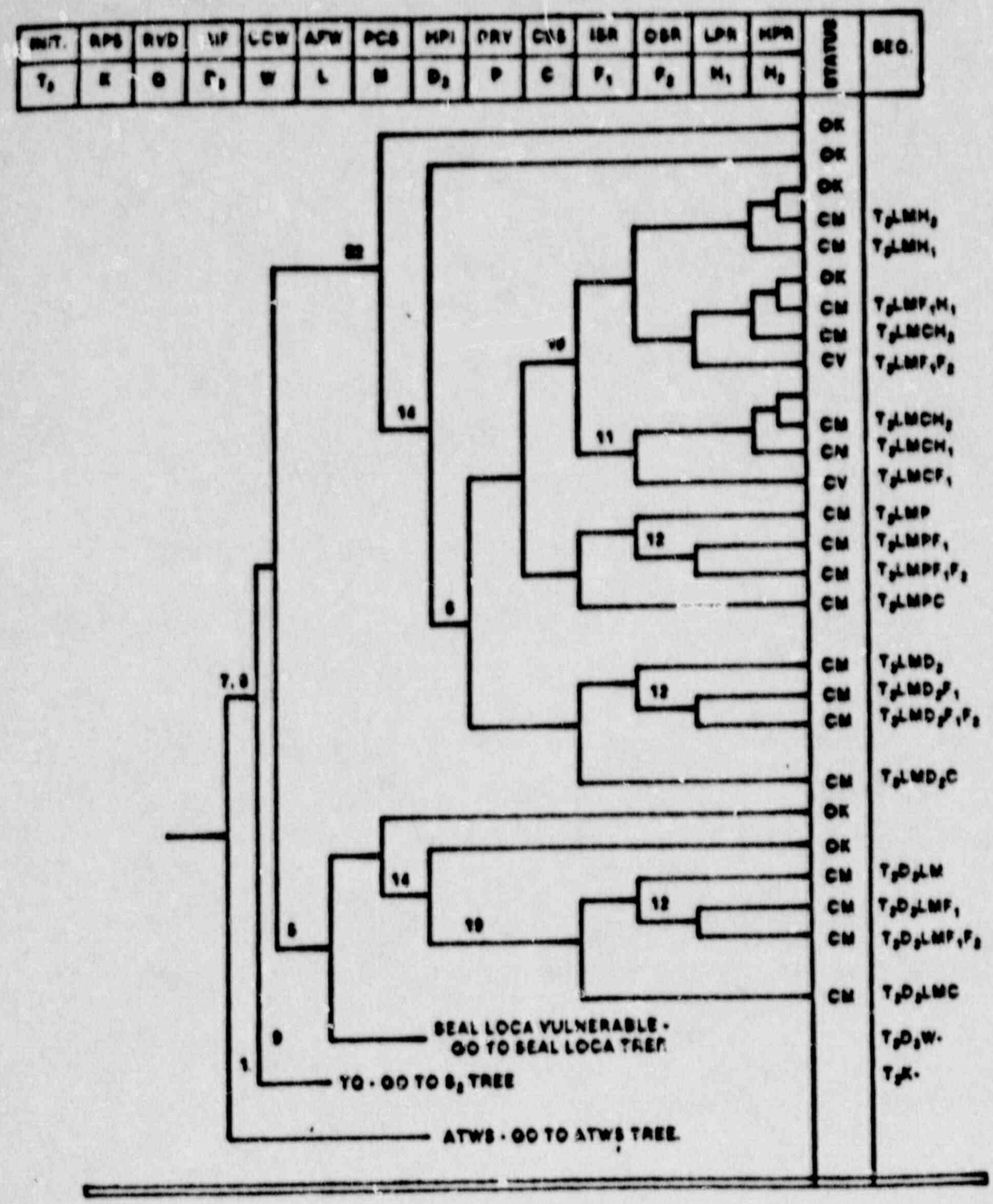


Figure 6

Event Tree for T_3 - Turbine Trip

with MFW Initially Available

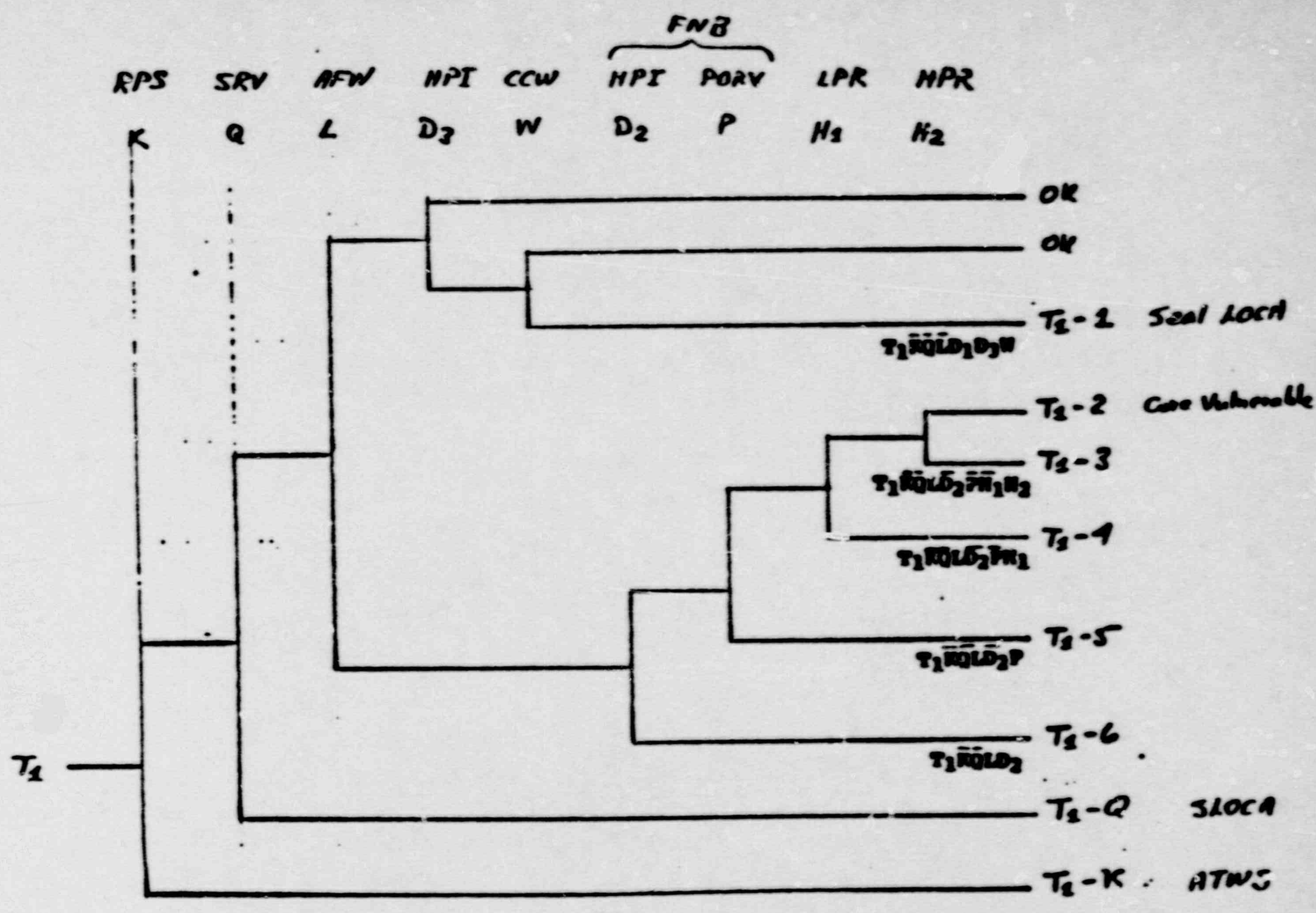


Figure 7 T_1 (Loss of Offsite Power) Seismic Event Tree

These logic models are combined using Boolean algebra (as embodied, for example, in the SETS computer code, Reference 5) to give an expression for each accident scenario (accident sequence) in terms of combinations of component failures. These combinations of basic component failures are called "cutsets". A typical accident sequence has the general form

$$Acc = C_1 + C_2*C_3 + C_4*C_5*C_6 + \ldots\ldots$$

where the C_i are component failures. Note that this is a Boolean logic equation in which the "+" denotes the logical union operator and the "*" denotes the logical intersection operator. (It is not until later that the equation is converted into an algebraic equation for quantification.) The occurrence of the failure events in any one cutset results in the occurrence of the accident sequence. Once numerical values for the basic component failure events are determined (from some data base) the frequency of the accident sequence can be found using the laws of probability to evaluate the cutsets and the union of the cutsets. (The existence of correlation between the basic component failure events must also be considered in this process.) The final result is a numerical value for the frequency of each accident sequence, and the frequency of core damage is determined from the sum of the accident sequence frequencies.

In a vital area analysis, the same process is used, except that the goal is to determine which areas in the plant are vital in the sense that if some or all components in a single area or combination of areas were failed due to some cause (i.e., a fire, flood, etc.) then core damage would result. This is accomplished by mapping each susceptible component (and its associated cables) occurring on the fault trees to the area in which they reside, and using the laws of Boolean logic to obtain logic expressions for the accident sequences in terms of the locations (hereafter referred to as fire zones) and random failure events. The general form for each accident sequence is

$$Acc = Zone\ 1 + Zone\ 2*Zone\ 3 + Zone\ 4*Random\ 1 + \ldots\ldots$$

where Zone 1, Zone 2, etc., are the locations and Random 1, Random 2, etc., denote random failures or test/maintenance unavailabilities. This form of the accident sequences is obtained using the Boolean mapping option in the SETS code in conjunction with tables relating each component to its location. As part of the solution process, numerical screening is performed so that only probabilistically significant cutsets are retained. The value of the numerical cutoff is specified by the analyst, and is chosen to be consistent with the remainder of the PRA for the plant in question.

This form of the accident sequence can be used to perform a quantitative assessment of the impact of an inadvertent FSS activation in any particular area, including the concurrent unavailability of equipment located in other areas due to random causes. In addition, this form of the equation yields qualitative insights directly useful to the plant operator, as those areas which are single point vulnerabilities are identified directly. This can be used as a basis for reviewing the critical equipment in those areas for vulnerability to any hazards which might conceivably be postulated in that area.

In the following sections, criteria are given for utilizing these very general accident sequence vital area equations to evaluate the potential risk arising from inadvertent actuation of a plant's fire suppression systems, under a quite general set of root cause scenarios.

3.2 Generic Inadvertent FSS Actuation Scenarios

Based on the review of past experiences and walkdowns of a number of plants, ten generic root cause scenarios were identified, as shown in Table 5. Three root causes are due to inadvertent FSS actuations caused by a fire in another area. Three are due to such actuations resulting from purely random causes. Three are due to seismic causes, and finally, one is due to the occurrence of a fire outside the plant. In the following, the various root causes of inadvertent FSS actuation are described and the specific tasks and information required to evaluate them are briefly discussed:

1. Fire-induced FSS actuation - FSS agent induced damage. Based on the vital area analysis and an Appendix R review, one would identify areas where smoke spread could cause inadvertent actuation given a fire, and conservatively estimate the impact of the FSS agent on equipment in the adjacent room and add a cutset to the appropriate accident sequence and requantify the sequence.

2. Fire-induced FSS actuation-recovery prevention. The plant's PRA is reviewed for risk-significant recovery actions on equipment not damaged by fire. Then, the various fire areas are examined for those from which smoke could spread and prevent the recovery action hypothesized. If any such combinations are found, the accident sequence is requantified with the probability of nonrecovery equal to unity.

3. Fire-induced FSS actuation - access prevention. For each critical fire area identified in the fire PRA where manual fire suppression was identified as the means of mitigating the fire, access to the fire area would be identified via the Appendix R submittal. An estimate of the delay caused by the inadvertent FSS actuation would be used to change the probability of suppression used in the original PRA and the effect requantified.

TABLE 5

Potential Root Cause Scenarios Resulting from Inadvertent FSS Actuation

1. Fire-induced FSS actuation and damage due to fire in an adjacent area.

2. Fire-induced FSS actuation (due to fire in an adjacent area) preventing random failure recovery actions.

3. Fire-induced FSS actuation (due to fire in an adjacent area) preventing access for manual fire suppression.

4. Random FSS actuation caused by human error.

5. Random FSS actuation caused by steam pipe break.

6. Random FSS actuation caused by random failures of FSS components.

7. Seismic inadvertent FSS actuations resulting from dust-triggered FSS.

8. Seismic inadvertent FSS actuations caused by FSS relay chatter.

9. Seismic inadvertent FSS actuations resulting from seismic-caused failures of FSS.

10. Fire's external to plant causing inadvertent FSS actuations.

4. Random FSS actuation - human error. Quantification requires identification of personnel options for actuating the FSS from both the control and remote locations and to identify possible multiple FSS actuations. The accident sequence cutsets are analyzed to determine if equipment damage by the FSS agent could lead to core damage. Then, those cutsets requiring a single FSS actuation are quantified by using an estimate of the frequency of inadvertent FSS actuations cause by random human error. For those cutsets requiring multiple FSS actuations, a fire in one of the areas is assumed, and a conservative estimate of the probability of human error actuation of suppression systems in other areas is applied.

5. Random FSS Actuation - steam pipe break. Again, quantification of this scenario requires an existing vital area analysis in conjunction with the knowledge of the presence of high temperature steam or water pipes in the zones. A conservative estimate of the pipe failure frequency and the potential for causing inadvertent fire suppression system actuations has to be made. A conservative estimate of the probability of steam reaching adjacent rooms and causing FSS actuations is also applied.

6. Random inadvertent FSS actuation - random failures of FSS. In this scenario, inadvertent actuation of the FSS is caused by purely random failures of the FSS itself, such as a pipe break in a deluge system, or a failure in an FSS control circuit. Frequencies for such events must be obtained from the historical data base of such events for different types of systems. Using these frequencies and a conservative estimate of the FSS agent's effect on nearby equipment, the accident sequences are requantified.

7. Seismic inadvertent FSS actuation - dust. Those fire areas utilizing smoke/particulate detectors are identified. Then dust is assumed to cause FSS actuation in the fire zone. Vulnerable equipment in the fire zone is identified and assumed failed. These failures are added to the seismic sequences and requantified.

8. Seismic inadvertent FSS actuation - relay chatter. Relay chatter is assumed to cause actuation of all fire suppression systems having automatic actuation circuitry. Conservative assumptions are made as to the effect of the insdvertent suppression system actuation on functionality of the equipment. These failures are added to the seismic sequences and requantified.

9. Seismic inadvertent FSS actuation - seismic failures. This cause is highly plant specific and it requires one or more plant visits in order to assess the potential vulnerability of the plant's FSS components to seismic events. However, the vital area equations can again be used directly to assess the impact of such events.

10. External fire-caused inadvertent FSS actuation. An estimate of frequency of external fires based on generic data must be made. Fire zones potentially affected by an external fire are identified. Any potential accident sequences are identified and, if non-negligible, the sequences are requantified.

To identify the critical areas, criteria were developed for each root cause scenario which enable the analyst to determine which areas are potentially subject to each root cause of inadvertent FSS actuation, given the general vital area analysis accident sequence equations. These criteria are shown on Table 6. This step is performed manually, and requires a review of plant systems, plant layouts, and the Appendix R submittal for the plant in light of the Task 1 results. This review must consider such factors as:

a) the presence of automatic suppression systems,
b) physical and electrical separation of redundant trains,
c) susceptibility to seismic events,
d) propagation of combustion products (generated either inside or outside the plant) through the ventilation system,
e) possible water and steam ingress into vulnerable equipment
f) single random actuations of FSSs,
g) multiple actuations of FSSs.
h) type of fire detectors.

Since all of the desired information may not be readily available, some plant input may have to be solicited.

3.3 Quantification

Quantification of the probability of these scenarios requires determination of the following:

Table 6

Inadvertent Fire Suppression System
Actuation Root Cause Scenarios

Root Cause 1 Fire-induced FSS Actuation Due To Smoke Spread

Event Sequence:	Fire in Room A; Smoke travels and actuates Suppression system in Room B; Suppression system damages critical equipment in Room B
Cutset Criteria:	At least one Fire Zone having a Fire Suppression System (manual or automatic) and smoke detectors; no more than one Fire Zone without FSS and smoke detectors; reasonable access for smoke to enter Room B from Room A

Root Cause 2 Fire-induced FSS Actuation Preventing Recovery

Event Sequence:	Fire in Room A; Smoke travels and actuates Suppression system in Room B; Suppression system prevents risk-significant recovery action from being performed in Room B
Cutset Criteria:	This is a cutset involving a fire zone in conjunction with one or more random failures. A recovery action (for a random failure) is in a fire zone with a fire suppression system and potential connectivity to the fire zone postulated to experience a fire.

Root Cause 3 Fire-induced FSS Actuation Preventing Fire-fighting Access

Event Sequence:	Fire in Room A; Smoke travels and actuates FSS in Room B; Suppression system prevents access to Room A for manual fire fighting
Cutset Criteria:	A Fire Zone accessible through only one other Fire Zone having a Fire Suppression System (manual or automatic) and smoke detectors; only one Fire Zone without FSS; manual fire fighting in Room A must be significant in reducing CDF.

Table 6 (Cont'd)

<u>Root Cause 4 FSS Actuation Caused By Human Error</u>

Event Sequence:	Operator (in Control Room or locally) erroneously actuates FSS in room or rooms without fire (possibly because of a detector alarm); Suppression system damages critical equipment in affected Fire Zones
Cutset Criteria:	All Fire Zones in cutset have Suppression Systems capable of being actuated from one control panel (in the Control Room or locally)

<u>Root Cause 5 FSS Actuation Caused By Pipe Break</u>

Event Sequence:	Failure of steam/hot water pipe releases steam which actuates (automatically or manually) nearby Fire Suppression System; FSS then damages nearby critical equipment
Cutset Criteria:	Two types of cutsets are significant here. First, a cutset involving a fire zone which contains both an FSS and a steam pipe. Second, a zone with an FSS which is adjacent to another fire zone containing a steam source, with a potential for steam spread between the zones.

<u>Root Cause 6 FSS Actuation Caused By Random Failures In FSS</u>

Event Sequence:	Failure of Fire Suppression System component causes actuation of FSS in Fire Zone; FSS then damages nearby equipment.
Cutset Criteria:	All Fire Zones in cutset have FSS (manual or automatic); no Fire Zones without FSS; if more than one Fire Zone in cutset, possible common cause failure for multiple actuations.

Table 6 (Cont'd)

Root Cause 7 Dust-Triggered FSS Actuations In Seismic Events

Event Sequence:	Seismic event stirs up dust which actuates automatic FSS using dust-sensitive detectors; FSS then damages nearby equipment
Cutset Criteria:	All Fire Zones in cutset have an automatic FSS triggered by dust-sensitive (photo-electric or ionization) detectors; no Fire Zones without FSS.

Root Cause 8 Relay Chatter FSS Actuations In Seismic Events

Event Sequence:	Seismic event causes relay chatter in vulnerable FSS control circuits; FSS actuates and damages nearby equipment
Cutset Criteria:	All Fire zones in cutset have a FSS (manual or automatic) that has relays in control circuitry; no Fire zones without FSS

Root Cause 9 FSS Actuations Due To Seismic Failures Of FSS

Event Sequence:	Seismic event causes failure of FSS components; Suppression agent is released and damages nearby equipment
Cutset Criteria:	All Fire Zones in cutset have a FSS (manual or automatic); no Fire Zones without FSS

Root Cause 10 External Plant Fires Causing FSS Actuations

Event Sequence:	Fire outside the plant generates smoke; Smoke is drawn into plant ventilation system; smoke actuates detectors and FSS in rooms serviced by outside ventilation; FSS damages plant equipment
Cutset Criteria:	All Fire Zones have a FSS (manual or automatic) and smoke detectors; all Fire Zones receive unfiltered outside ventilation; no Fire Zones without FSS

a) Frequency of fires in zones (Root causes 1,2,3)
b) Frequency of human error of commission (Root cause 4)
c) Probability of barrier failure (for smoke spread)
d) Probability of FSS actuation damaging equipment
e) Probability of additional random failures, if required
f) Probability of non-recovery, if required
g) Probability of FSS random failure (Root Cause 6)
h) Frequency of steam pipe break (Root Cause 5)
i) Frequency of fires external to the plant (Root Cause 10)

The specific equations used to quantify each root cause scenario are given on Table 7. Parameter values used to perform the scoping quantifications are described below.

3.4 Generic Scoping Quantification Data

The purpose of this study was to provide a scoping quantification of the potential impact on risk of inadvertent actuations of fire suppression systems. In general, in such a study, values chosen for the various parameters involved should be best-estimate values based on data. In this study, no plant specific data analysis was performed. However, in some cases, historical data were used to estimate numerical values. Where no data was available, conservative numerical values were estimated based on the authors' collective judgement, as noted below.

3.4.1 Fire Occurrence Frequencies

A data base of fire occurrence frequencies was developed in Reference 2 for a variety of prototypical nuclear power plant buildings (e.g., auxiliary building, turbine building, emergency switchgear rooms, diesel generator rooms, etc.) based on the history of significant fires in commercial nuclear power plants as contained in the US NRC Licensee Event Reports. These generic frequencies (per year) were used in this study. Specific mean values are:

Auxiliary Building	6.4 E-2	per Rx-year
Turbine Building	3.2 E-2	per Rx-year
Diesel Generator Building	2.3 E-2	per Rx-year
Emergency Switchgear Room	3.0 E-3	per Rx-year
Cable Spreading Room	2.7 E-3	per Rx-year
Battery Room	3.0 E-3	per Rx-year
Control Room	4.4 E-3	per Rx-year
Reactor Building	1.8 E-2	per Rx-year

Table 7

Equations Used in Quantification of Inadvertent FSS Actuation Core Damage Sequences

Definitions:

ϕ_{cm} = frequency of cutset core damage
P(dam) = probability of FSS damaging critical equipment
P(BF) = probability of fire barrier failure
P(rand) = probability of other random failures that contribute to core damage
P(nr) = probability of non-recovery, if applicable
P(LOSP) = probability of seismic loss of offsite power

ROOT CAUSE 1:

ϕ_{cm} = frequency(fire in adjacent areas) * P(BF) * P(dam) * P(rand)*P(nr)

or, if the cutset contains two fire zones,

ϕ_{cm} = frequency(fire in area without FSS) * P(BF) * P(dam) * P(rand)*P(nr)

ROOT CAUSE 2:

ϕ_{cm} = frequency(fire in area in cutset) * P(BF) * P(rand)*P(nr)

ROOT CAUSE 3:

ϕ_{cm} =frequency(fire in area in cutset)*P(BF)* P(non-suppression of fire damage)*P(rand)*P(nr)

ROOT CAUSE 4:

ϕ_{cm} = [frequency(human error FSS actuation)/number of Surry fire zones with FSS] * P(dam) * P(rand)*P(nr)

or, if the cutset contains two fire zones,

ϕ_{cm} = [frequency(fire in first area) * P(human error actuation of FSS in second area) * P(damage in second area) + frequency(fire in second area) * P(human error actuation of FSS in first area) * P(damage in first area)] * P(rand)*P(nr)

ROOT CAUSE 5:

ϕ_{cm} = frequency(steam pipe break in area 17 or 31) * probability(barrier failure to steam) * P(dam) * P(rand)*P(nr)

ROOT CAUSE 6:

ϕ_{cm} = [frequency(actuation failure of each type of FSS)/number of each type of FSS at Surry] * Number(each type of FSS in area) * P(dam) * P(rand)*P(nr)

ROOT CAUSE 7:

ϕ_{cm} = P(LOSP)*P(FSS actuates in zone due to dust)*P(dam)

ROOT CAUSE 8:

ϕ_{cm} = P(LOSP)*P(FSS failures in zone)*P(dam)

ROOT CAUSE 9:

ϕ_{cm} = P(LOSP)*P(relay chatter FSS actuation)*P(dam)

ROOT CAUSE 10:

For fire areas served by unfiltered, outside air:

ϕ_{cm} = frequency(large fires near plant) * P(smoke blowing toward plant) * P(dam) * P(rand)*P(nr)

Note that for the generic buildings, it is often necessary to ratio the overall building fire occurrence frequency down to reflect the fact that fires in only a small subset of the building can cause the postulated damage. This is called "partitioning" and is based on both analyst judgement and sensitivity calculations using a fire growth computer code.

3.4.2 Effect of FSS Actuation on Equipment

Very little data exist on the effects of the FSS agents on various types of equipment. The LER review described earlier yielded the following insights:

a) 1 of 9 CO_2 reported actuations caused some equipment damage

b) 0 of 9 Halon reported actuations caused equipment damage

c) 40% of deluge reported actuations caused some equipment damage

Based on this limited set of observations, the probability of damage to active electro-mechanical equipment and to cables (and their associated electrical penetrations, terminal blocks, etc.) was taken as 0.1 per exposure. This is clearly conservative for Halon systems, and probably a bit non-conservative for deluge systems, although the latter will be highly dependent on the effectiveness of the equipment qualification testing program implemented at the plant.

The reason for applying the same probability to both CO_2 and Halon systems is that they both involve the release of pressurized gas. The one case of equipment damage from CO_2 was due to the cold temperature resulting from release of excessive amounts of gas and not the type of gas. Indeed, if it can be shown for a particular plant that such an "overdump" is impossible, the probability of damage from CO_2 or Halon can be lowered significantly.

Note that in estimating the conditional probability of failure of equipment exposed to the FSS agent, one must take into account the type of system involved. For example, inadvertent actuation of a CO_2 or Halon system in a diesel generator room often requires the room to be sealed off (which is accomplished automatically), so that the necessary concentrations of fire suppression agent can be obtained. Without room ventilation, diesel failures due to room temperature increases (which result from diesel operation) are likely. In this case, the conditional probability of damage should be taken as 1.0, instead of using the value of 0.1 described above.

3.4.3 Probability of Barrier Failure

A generic probability of failure of a fire barrier between two fire zones was taken from the values used for the NUREG-1150 fire PRAs (Reference 6). This value was assumed to be 0.1 for all fire zones.

The basis for this assumption is as follows. From past NRC I&E Inspector reports (Reference 6), typical values for failure rates for barriers are as shown below:

Barrier Type	Failure Rate
Fire doors and curtains	7.4E-3
Ventilation and fire dampers	2.7E-3
Fire walls and Penetrations	1.2E-3

These barrier failure probabilities could be multiplied by the number of each type of barrier and then summed to give the probability of barrier failure and smoke spread for any particular fire zone. However, this requires a plant specific examination of each fire zone to determine the number and type of barriers present, which was beyond the scope of this study. Based on our experience in past plant visits, a reasonable number of such barriers (on average) is 10 per fire zone. Thus the value of 0.1 per demand was selected for a generic barrier failure rate. The same failure rate was assumed to apply to barrier failure in the presence of either smoke or steam.

3.4.4 Inadvertent FSS Actuation Due To Human Error of Commission

Very little data exists on this possible root cause. Based on the LER search described above, a value of 0.06 per reactor year was chosen. This value should be divided by the number of fire suppression systems installed at a particular plant to obtain a system-specific frequency.

3.4.5 Random Failure and Human Error Values

The random failure rates and the human error probabilities must be taken from the plant specific PRA for the plant under consideration. Random failure rates are very much dependent on the operating history of component failures at the plant in question, while human error probabilities are very much dependent on the layout of the plant systems involved in the human recovery action postulated. Thus, in general, the values developed for the original PRA should be used for the random and human error events occurring in the vital area analysis cutsets.

Modifications to the human error probabilities should be made in the case of recovery actions which must be performed in a fire zone in which either a fire has occurred or in which significant heat or smoke are present. Such recovery actions are usually denoted as "high stress actions" and procedures are available to develop modifying factors to reflect high stress situations, as for example in Reference 7.

For the study reported here, all human actions were taken directly from the original internal events PRA with the exception of (a) recovery from the remote shutdown panel and (b) cross-connection of the Unit 2 HPI system given that a fire has occurred in an area where a local recovery action must be performed. Numerical values for all recovery actions are given for each cutset in Appendix B.

3.4.6 Inadvertent FSS Actuation Due to Random Failure of FSS

Again, very little data exists on the frequency of this occurrence and the LER review described earlier was used to calculate this frequency. Since it was assumed that the FSS failure rate is dependent on the type of suppression system, different frequencies were calculated for each of the different systems.

On a per reactor-year basis, the frequencies chosen were 0.025 for water based systems (deluge, sprinklers, water curtain, etc.), 0.0077 for CO_2, and 0.0019 for Halon.

3.4.7 Random Steam Pipe Break

Limited data exist on the frequency of steam and hot-water pipe break. A generic value of 0.003 breaks per reactor-year (as used in other studies, eg., Reference 8, 9) was chosen. This value is based on all high pressure piping in a plant, and for a plant-specific study could be ratioed down to only that piping whose failure could affect one of the FSS systems. (This was not done for this study, which represents a source of conservatism).

3.4.8 Frequency of External Fires

Since this value is highly dependent on the topography, vegetation, and climate near the plant, no attempt was made to pick a generic value.

3.5 Quantification of Seismic FSS Actuations

As mentioned above, the seismic sequences which must be considered are those with offsite power assumed to be lost as shown on Figure 7. Once the vital area analysis has been performed for the LOSP sequences, one can quantify them in a similar fashion as was done for the random and fire-induced FSS actuation scenarios. The one significant difference is that the accident sequences so evaluated are conditional on the plant site seismic hazard curve, so that the accident sequence conditional frequencies must be integrated over the hazard curve (Reference 10) using the equation

$$F(Acc) = \int P(Acc)*f_h(pga)d(pga)$$

where

F(Acc) = total frequency of accident sequence due to the weighted probability of all earthquake levels.

P(Acc) = conditional accident sequence frequency

f_h(pga) = density function for the seismic hazard curve as a function of peak ground acceleration (pga)

In computing the conditional frequencies of accident frequencies resulting from inadvertent actuation in the fire zones in the vital area analysis equations, one must take into account the root cause being considered.

3.5.1 FSS Actuation By Dust Raised In A Seismic Event

This root cause should only be considered for those fire zones in which the FSS is automatically actuated by smoke detectors, and hence would possibly be actuated by dust raised during a seismic event. If included, the conditional probability of inadvertent FSS actuation given a seismic event should be taken as 1.0. If more than one fire zone is being considered for this root cause, then the inadvertent actuations should be considered as fully correlated, ie., all FSSs should be assumed to be actuated simultaneously in each affected fire zone.

3.5.2 FSS Actuation Due To Seismically-Induced Failures In The FSS

For inadvertent FSS actuations brought about by seismic failures of the various components of the FSS systems, it is, in general, necessary to "walk down" each FSS during a visit to the plant, and identify the various components in the system. Then a system fragility function can be developed from the failure levels for the individual components themselves. Procedures for developing such seismic fragility functions are described in Reference 11. In addition, since the typical components in a FSS are pipes, valves, nozzles, solenoids, electric motor pumps and electrical control cabinets, it may sometimes be possible to use generic fragility functions for these components as contained in Reference 11. This must be done with caution, however, for components in the generic data base referenced are typically seismically qualified, while seismic qualification has not been required for FSS components in the past (with the exception of water standpipes in rooms containing safety equipment). In particular, socket welded pipe joints and threaded pipe joints are not used in safety grade piping, while such joints are typically used in fire protection pipes.

A crude alternate approach (used in this study) is to use a log normal fragility function specified to have a median acceleration at failure equal to twice the safe shutdown earthquake (SSE) level for the plant site. This is based on the author's experience in walking down a number of these systems, and for most FSSs, should be conservative. The two uncertainty parameters for this log normal fragility distribution can be taken as Beta-r = 0.3 and Beta-u = 0.3 in the notation of Reference 11. The local response should be the peak ground acceleration amplified by 20% to allow for some structural amplification, and the corresponding uncertainty parameters can be taken as Beta-r = 0.35 and Beta-u = 0.25 which are appropriate for uncertainties in amplified floor zero period acceleration (Reference 6). This approach should only be used in cases (such as this study) where time and budgetary constraints prevent developing defensible fragility functions for the FSSs involved. Note that the plant under consideration had an SSE equal to 0.15g, and thus the median fragility value was taken as 0.30g.

Finally, one must take into account the different types of systems involved. For example, in Halon or CO_2 systems, a failure of piping which delivers the FSS agent to the fire zone would not cause inadvertent actuation inasmuch as the agent has not been released. By contrast for certain types of sprinkler systems, the pipes are full of water at all times, and hence, failure would result in release of water on equipment below.

3.5.3 FSS Actuation Due To Seismically-Induced Relay Chatter

For relay chatter-induced FSS actuations, the fragility function for generic relay chatter from Reference 11 can be used. This fragility curve (as a function of local floor acceleration) has a median acceleration at failure of 4.0g (spectral acceleration in 5-10Hz range) with uncertainty parameters Beta-r = 0.48 and Beta-u = 0.75. In this case, one must determine which of the FSS systems will be activated due to relay chatter, which requires identification of the vulnerable relays used in the FSS control circuits and an evaluation of the control circuits themselves for "locking logic". Inasmuch as relay chatter is expected to occur at relatively low seismic shaking levels and to occur in all control circuits at the same time, in evaluating the accident sequences, one should assume all FSS actuations are fully correlated, and occur simultaneously given that relay chatter has occurred.

Of course, this assumes that the circuitry is such that momentary chatter will activate the FSS system (i.e., there are locking circuits involved). No study of the circuitry of typical control systems for the FSSs of the plant under consideration was made in this project. Until this is done, the above assumption (that momentary chatter will actuate <u>all</u> suppression systems) must be made for these scoping quantifications. This assumption is reasonable from the viewpoint that earthquakes are known to cause many types of relays to chatter, and due to the common-cause nature of the ground shaking associated with earthquakes. However, this assumption may be unduly pessimistic because not all FSS control circuits may be actuated by momentary chatter.

3.6 Summary

A methodology has been developed which can be applied to any plant for which a vital area analysis is available. If such a vital area analysis is not available, one can be developed in a fairly straightforward manner provided a systems analysis of the plant (as embodied in event trees and fault trees) has been completed. Generic values for the various failure rates needed have been estimated. However, for any specific plant, much improved estimates of many of the parameters could be obtained. A continuing need exists for actual data on the effect of FSS agents on different types of equipment (both with and without the presence of a fire), for barrier failure rates in the presence of smoke and steam, and for identification of typical seismic vulnerabilities of fire suppression system components.

4.0 APPLICATION TO A PROTOTYPICAL PWR POWER PLANT

4.1 Introduction

The goal of Phase II of this study was to quantify the attendant contribution to core damage frequency (CDF) and risk resulting from inadvertent FSS actuations for specific nuclear power plant accident scenarios. Currently, the quantification process has been applied to a prototypical PWR. Inasmuch as the scenarios are plant-specific in regard to plant layout and types of fire suppression systems present, it was necessary to select an actual plant for the quantification of the scenarios. The physical layout and fire suppression systems configuration for the Surry PWR nuclear power plant were used because a detailed fire PRA and supporting analyses were available as part of the NRC-sponsored NUREG 1150 program (Reference 6). However, no plant-specific data analysis was performed, and no detailed analysis of the propagation of smoke within each room was performed to take into account the actual location of critical equipment in the room, and no plant-specific evaluation of the number and type of fire barriers in each zone was made. All of these factors significantly affect the quantitative results. Hence the results presented here should be viewed as being "reasonable" but not directly applicable to the Surry plant. This chapter describes the results of the scoping quantification analyses.

For these analyses, the configuration of equipment and fire suppression systems (FSS) at the Surry plant were reviewed. The potential root causes of inadvertent FSS actuations that could lead to core damage were identified. Based on the knowledge of the Surry FSS configuration, an initial scoping quantification of potential core damage sequences was performed.

4.2 Procedure

The initial phase of the analysis consisted of reviewing the Surry plant configuration. This was accomplished primarily by reviewing the Surry Appendix R submittal (Reference 12). From this submittal, information was obtained on the overall plant layout, on the individual Surry fire areas, on the particular types of FSS and fire detectors installed, and on the critical equipment required for safe shutdown. This information was used to determine those critical areas of interest for further study. A listing of all fire areas which resulted from the vital area analysis is given in Table 8. Only nine critical fire zones having automatic or manually actuated fire systems were identified. (This does not include manually-operated CO_2 bottles or water hose reels). These nine zones are:

Table 8

Fire Zones And Designators

FIRE AREA NUMBER	FIRE AREA NAME
Fire Area 1	Unit 1 Cable Vault and Tunnel
Fire Area 2	Unit 2 Cable Vault and Tunnel
Fire Area 3	Unit 1 Emergency Switchgear Room
Fire Area 4	Unit 2 Emergency Switchgear Room
Fire Area 5	Control Room
Fire Area 6	Emergency Diesel Generator Room #1
Fire Area 7	Emergency Diesel Generator Room #2
Fire Area 8	Emergency Diesel Generator Room #3
Fire Area 15	Unit 1 Reactor Containment
Fire Area 16	Unit 2 Reactor Containment
Fire Area 17	Auxiliary Building
Fire Area 19	Unit 1 Safeguards Area
Fire Area 20	Unit 2 Safeguards Area
Fire Area 31	Turbine Building
Fire Area 45	Mechanical Equipment Room #3
Fire Area 54	Charging Pump Service Water Pump Room

Cable Vault/Tunnel (FA-1, FA-2)

Emergency Switchgear Rooms (FA-3, FA-4)

Diesel Generator Rooms (FA-6, FA-7, FA-8)

Auxiliary Building (FA-17)

Turbine Building (FA-31)

These zones are listed in Table 9 along with the type of FSS, type of detectors, FSS actuation scheme, and critical equipment in the fire zone. Figures 8 through 14 illustrate these critical fire zones.

In several instances, the Appendix R information had to be supplemented by phone calls to plant personnel. Details on the locations of the equipment were obtained from tables generated as part of the NUREG 1150 Surry Fire PRA Study (Reference 6). The information in the Appendix R submittal was also used to determine the penetrations into each of the critical fire areas. Table 10 lists these fire areas and the doors and cables that connect them to other fire areas.

An additional document utilized was the Internal Events PRA for the Surry plant (Reference 4). The internal events report provided additional information on the Surry safe shutdown equipment and system models. This report also described safety-significant recovery actions from random failures. These recovery actions were then analyzed for the possibility that inadvertent FSS actuations could prevent them from being performed (See Cause 2 below). The Fire PRA provided probabilities of fires in the different areas, probabilities of fire area barrier failures, and estimated times to damage of critical equipment from fires in the different areas.

One subject that information could not be obtained on was the Surry ventilation system. Particular questions on this subject concerned the possible paths that smoke could travel from one fire area to another and from outside the plant structure into enclosed fire areas. Conversations with VEPCO personnel indicated that answering these questions would involve extensive engineering review of plant construction drawings. Consequently, consideration of smoke travel through the Surry ventilation system was not pursued at this time.

4.2.1 General Transients Caused By Fires Or Random Failures

Using the sequences and cutsets obtained from the vital area analysis for the Surry plant performed as part of the NUREG 1150 fire PRA (Reference 6), the various [illegible] to core damage were developed. Based on the ori[illegible] PRA, twelve general transient sequences had to [illegible] general transient event

Table 9

SURRY FIRE SUPPRESSION SYSTEMS AND SAFE SHUTDOWN EQUIPMENT BY FIRE ZONE

FIRE ZONE	SUPPRESSION SYSTEM
FIRE AREA 1 (Unit 1 Cable Vault and Tunnel)	Automatic CO2 activated by 6 Heat Detectors (with a backup manual actuation switch in Emergency Switchgear Room); Manually actuated Deluge (manual actuation involves turning valve handle) and manually actuated dry-pipe sprinkler system (having fusible links in sprinkler heads); also 8 ionization-type smoke detectors **SAFE SHUTDOWN EQUIPMENT** Numerous Cables for power, control, and instrumentation Motor Control Centers Cables for Charging Pumps (Nos. 1A, 1B, 1C) Cables for Charging Pump Cooling Water Pumps (Nos. 2A, 2B) Cables for Component Cooling Water Pumps (Nos. 1A, 1B) Cables for AFW Pumps (Nos. 2, 3A, 3B) Cables for Containment Spray Pumps (Nos. 1A, 1B) Cables for Low Pressure Safety Injection Pumps (Nos. 1A, 1B) Cables for Inside and Outside Spray Recirculation Pumps (Nos. 1A, 1B, 2A, 2B) Cables for Residual Heat Removal Pumps (Nos. 1A, 1B) AC Power Circuit Breakers (Nos. FE9BJ, FE9BK)
FIRE AREA 2 (Unit 2 Cable Vault and Tunnel)	**SUPPRESSION SYSTEM** Automatic CO2 activated by 6 Heat Detectors (with a backup manual actuation switch in Emergency Switchgear Room); Manually actuated Deluge (manual actuation involves turning valve handle) and manually actuated dry-pipe sprinkler system (having fusible links in sprinkler heads); also 8 ionization-type smoke detectors **SAFE SHUTDOWN EQUIPMENT** Cables and Controls for AFW Cross Connect Valve to Unit 1 Numerous Cables for power, control, and instrumentation Motor Control Centers
FIRE AREA 3	Halon system manually actuated either

(Unit 1 Emergency Switchgear Room)

locally or from control room panel #2; also, 10 ionization-type smoke detectors (Halon supply is 10 gas bottles designed to empty all their contents)

SAFE SHUTDOWN EQUIPMENT

Cables
Cables and Controls for Charging Pumps (Nos. 1A, 1B, 1C)
Cables and Controls for Charging Pump Cooling Water Pumps (Nos. 2A, 2B)
Cables and Controls for Component Cooling Water Pumps (Nos. 1A, 1B)
Cables and Controls for Charging Pump Service Water Pumps (Nos. 10A, 10B)
Cables and Controls for AFW Pumps (Nos. 2, 3A, 3B)
Cables and Controls for Containment Spray Pumps (Nos. 1A, 1B)
Cables and Controls for Low Pressure Safety Injection Pumps (Nos. 1A, 1B)
Cables and Controls for Inside and Outside Spray Recirculation Pumps (Nos. 1A, 1B, 2A, 2B)
Cables and Controls for Residual Heat Removal Pumps (Nos. 1A, 1B)
Numerous Switchgear & Relay Racks for safe shutdown equipment
Unit 1 Auxiliary Shutdown Panel
Several Vital AC and DC Power Busses and associated Circuit Breakers
Vital DC to AC Inverters and Rectifiers (#1-III, UPS-1, UPS-2)
Several Vital AC Transformers

Vital AC Buss feeders from Diesel Generators

DC Battery output and charger circuits

Emergency Communications System (repeater)

IRE AREA 4 (Unit 2 Emergency Switchgear Room)

Halon system manually actuated either locally or from control room panel #2; also, 12 ionization-type smoke detectors (Halon supply is 10 gas bottles designed to empty all their contents)

SAFE SHUTDOWN EQUIPMENT

Cables and Controls for AFW Cross Connect Valve to Unit 1
Numerous Switchgear & Relay Racks for Unit 2 safe shutdown equipment
Unit 2 Auxiliary Shutdown Panel
Cables
Emergency Communications System (repeater)

FIRE AREA 6 (Emergency Diesel Generator Rm #1)	Manually actuated low-pressure CO2 system (actuation switches are outside door and in Control Room on panel #1); also, 2 heat detectors

SAFE SHUTDOWN EQUIPMENT

Diesel Generator #1
Related Switchgear & MCC Cabinets

FIRE AREA 8 (Emergency Diesel Generator Rm #3)	Manually actuated low-pressure CO2 system (actuation switches are outside door and in Control Room on both panels #1 and 2); also, 2 heat detectors

SAFE SHUTDOWN EQUIPMENT

Diesel Generator #3
Related Switchgear & MCC Cabinets

FIRE AREA 17 (Auxiliary Building)	3 charcoal ventilation filters at 45 ft level, 2 of which have manually actuated low pressure CO2 systems (switches are next to filters and in Control Room on panel #2), and 1 of which has a manually actuated deluge (switch is next to filter); all 3 charcoal filter banks have heat detectors and the building has 38 ceiling-mounted ionization-type smoke detectors and 7 duct-mounted smoke detectors

SAFE SHUTDOWN EQUIPMENT

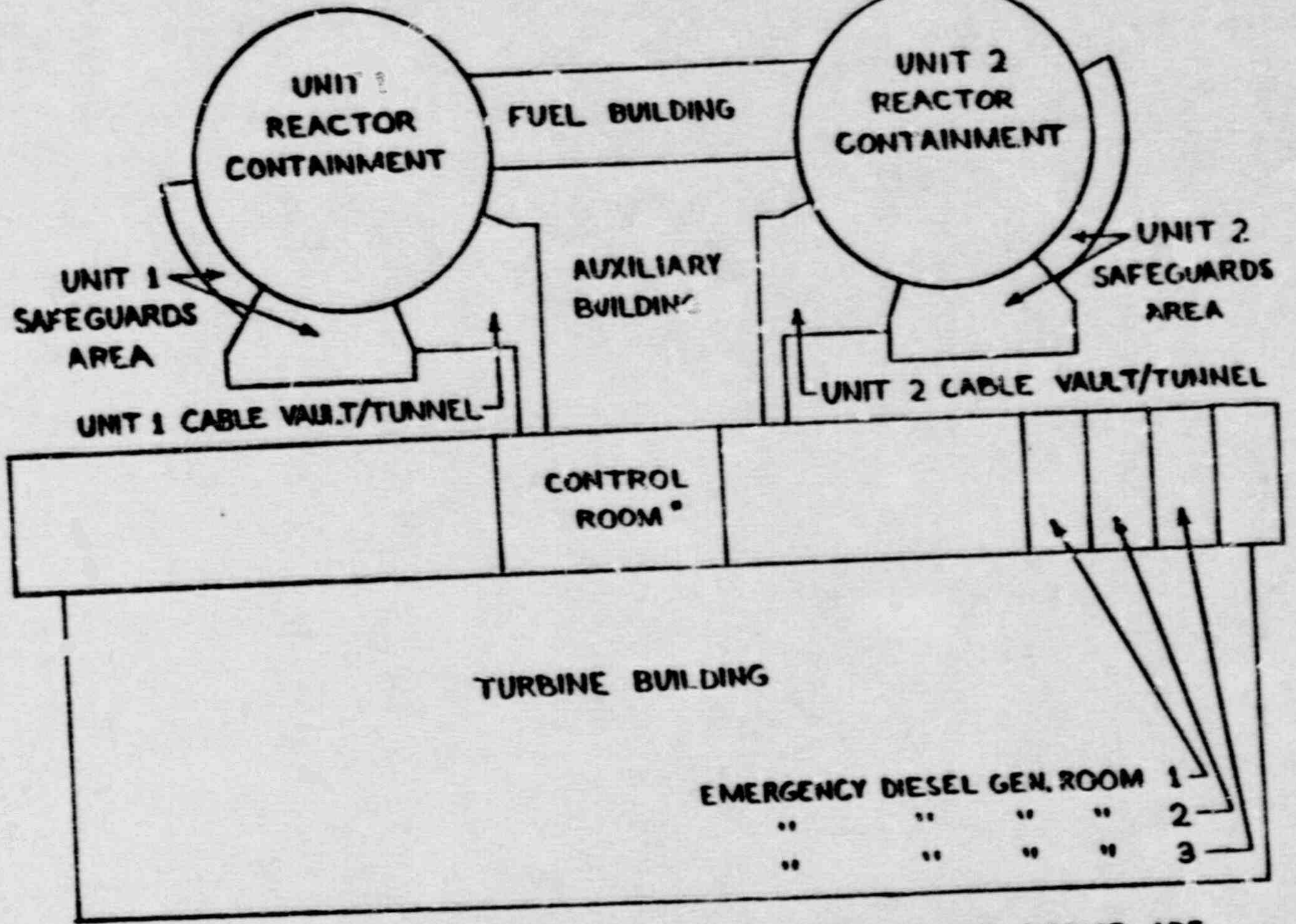
6 Charging Pumps(Nos. 1A,1B,1C, plus Unit 2)
4 Charging Pump-Component Cooling Water Pumps
(Nos. 2A & 2B plus Unit 2)
4 Component Cooling Water Pumps
(Nos. 1A & 1B plus Un 2)
Associated Cables & Valves for above pumps (esp
MOVs 1115B,1115C,1115D,1115E,1350,1867C,1867D)
Cables for indications at the Remote Monitoring Panel
Piping for charging pump service water
Ventilation for Auxiliary Bldg (Charcoal Filters)
Emergency Communications System (repeater)
Boric Acid Transfer Pump #CH2A

:E AREA 31 (Turbine Building)	Heat detector-actuated deluge system near lube oil components; automatic sprinklers in several areas including the corridors outside the Control Room and the Emergency Switchgear Rooms; automatic CO2 systems

actuated by heat detectors in Normal Switchgear rooms, Cable Spreading rooms, and general turbine area; also, several ionization-type smoke detectors

SAFE SHUTDOWN EQUIPMENT

Cables for Charging Pump Service Water Pumps (Nos. 10A, 10B)
Piping for charging pump service water system
Cables and Controls for AFW Motor Driven Pumps (Nos. 3A, 3B)
Cables and Controls for Containment Spray Pumps (No. 1A)
Cables and Controls for Low Pressure Safety Injection Pump (No. 1A)
Cables and Controls for Outside Spray Recirculation Pump (No. 2A)
Cables and Controls for Residual Heat Removal Pump (No. 1A)
Several Main Steam Valves (solenoid operated)
Circulating & Service Water motor-operated Valves
Auxiliary Steam System
Motor Operated Valves on the inlet and outlet of each Condenser
Remote Monitoring Panels
Emergency Communications System (repeater)



*- UNIT 1 AND UNIT 2 EMERGENCY SWITCHGEAR ROOMS ARE LOCATED BELOW THE CONTROL ROOM

Figure 8 Plant Layout

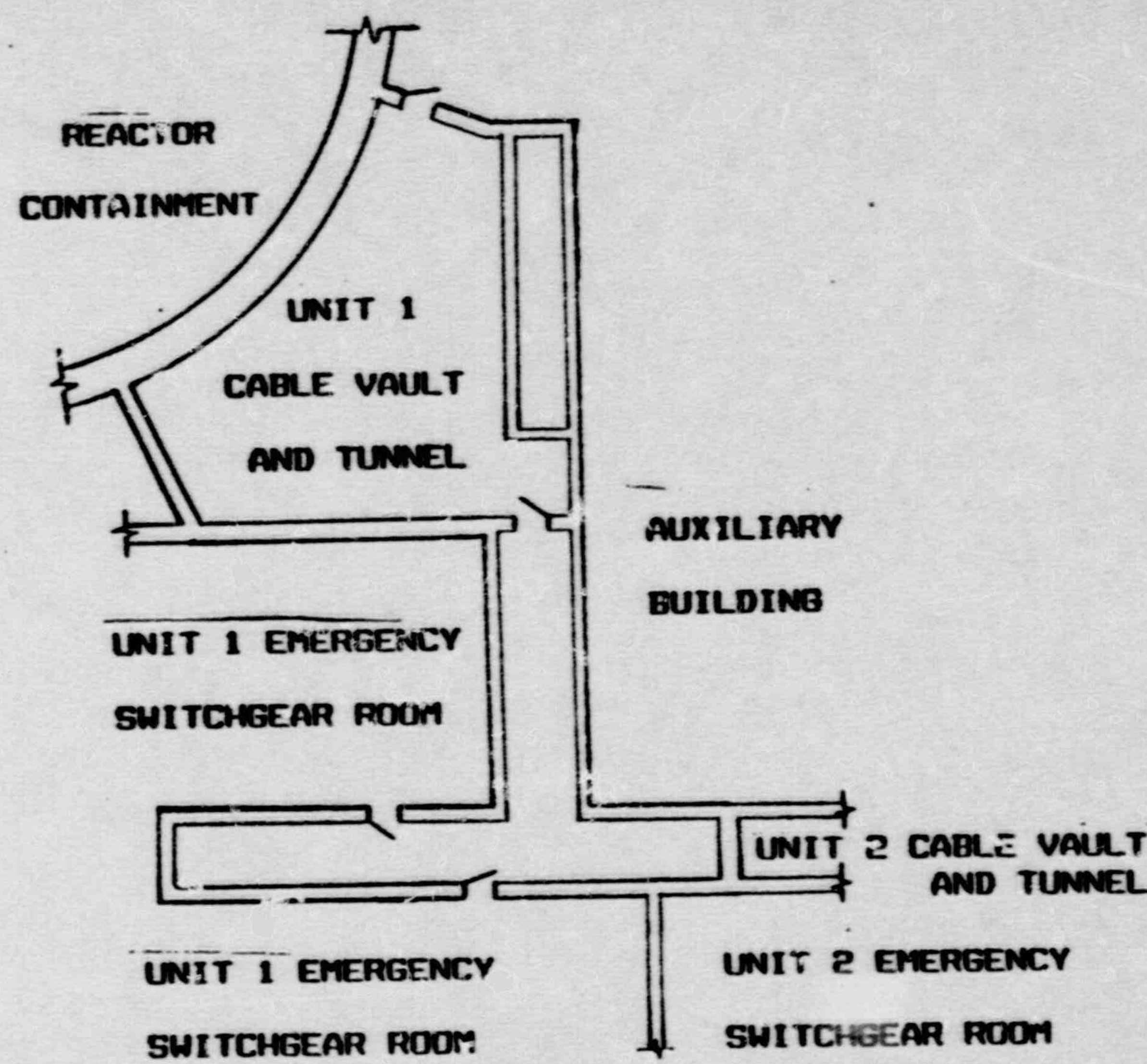


Figure 9 1 Cable Vault and Tunnel (Fire Area 1)

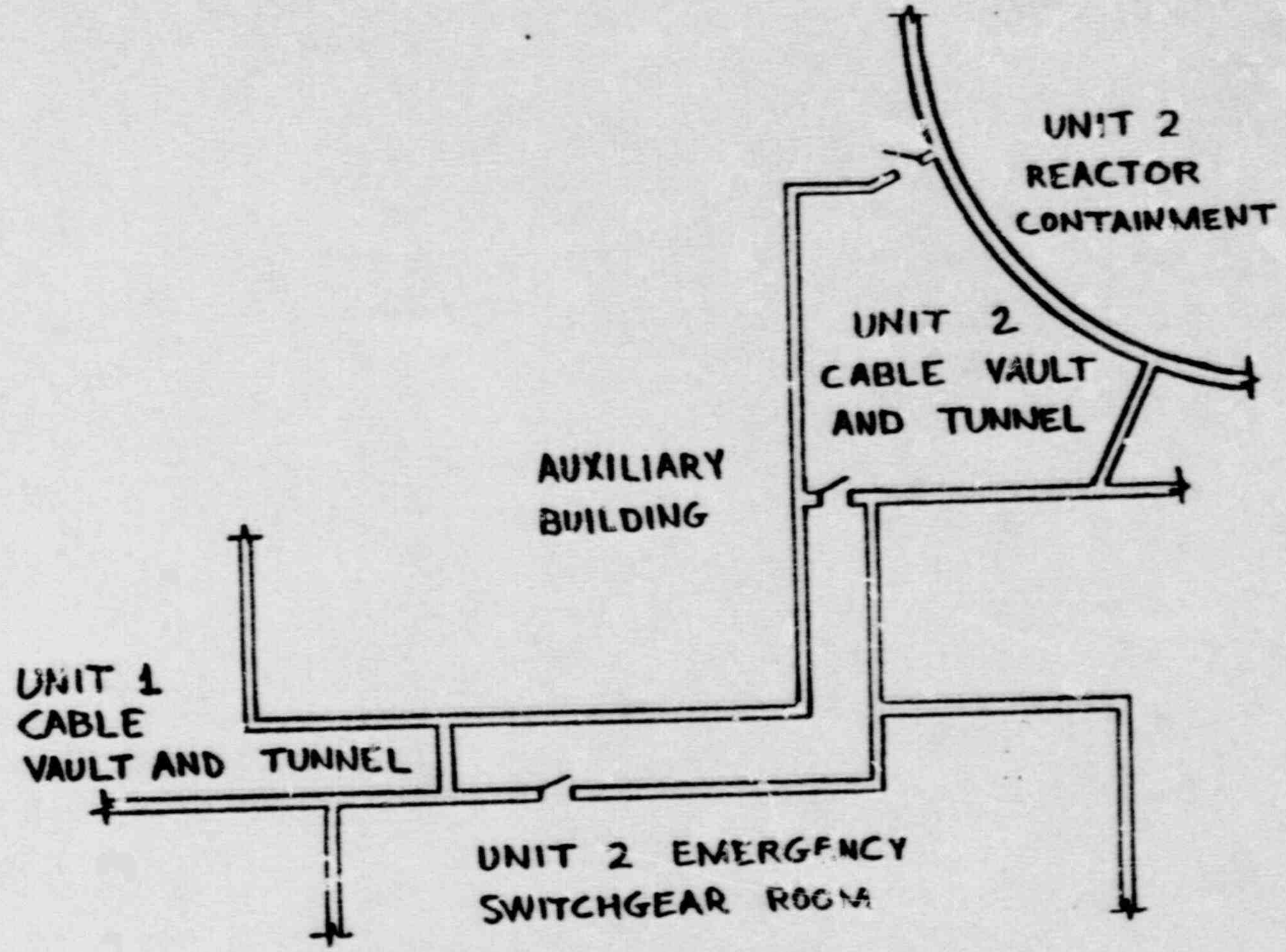


Figure 10 2 Cable Vault and Tunnel (Fire Area 2)

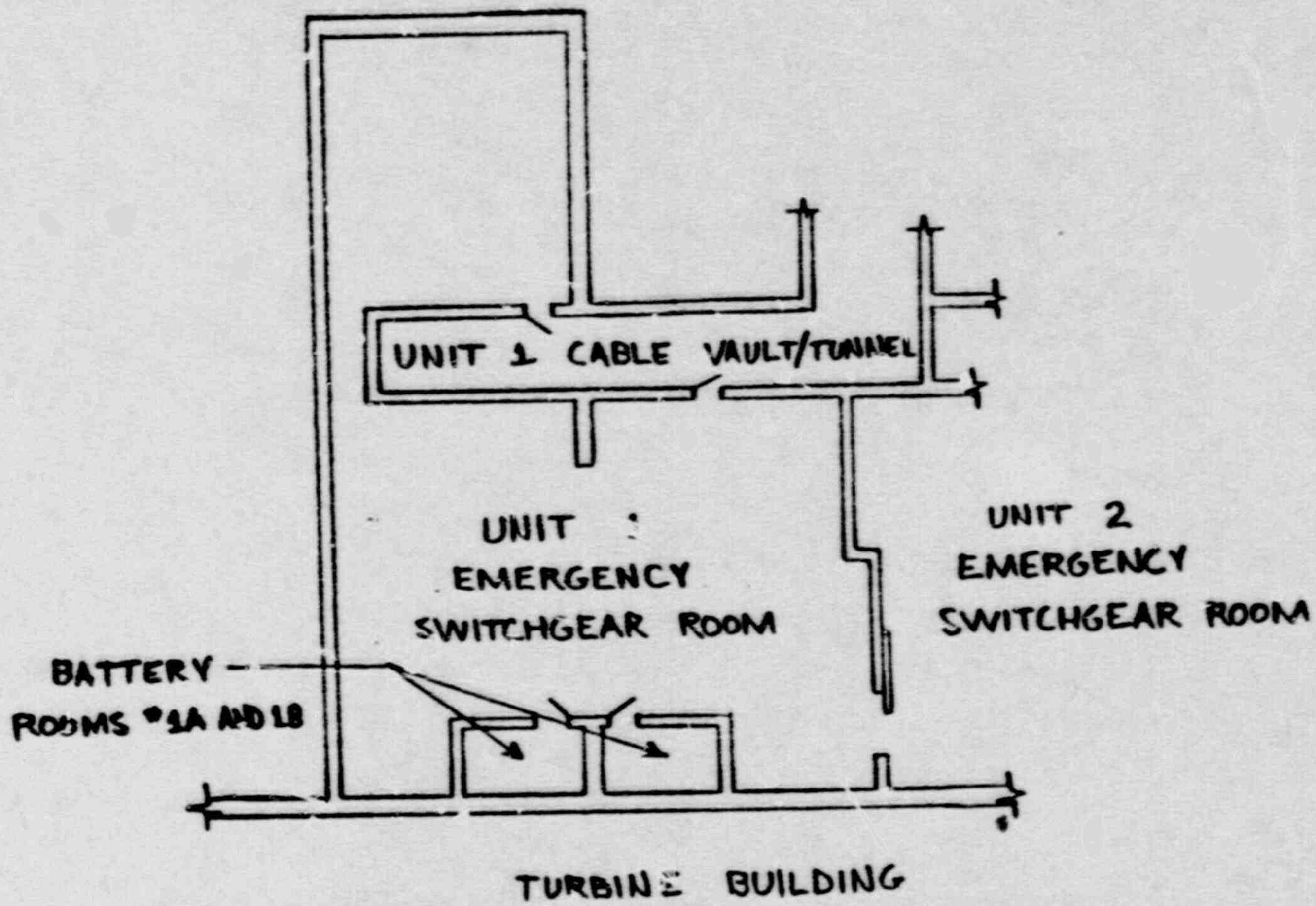


Figure 11

Figure 11 Unit 1 Emergency Switchgear Room (Fire Area 3)

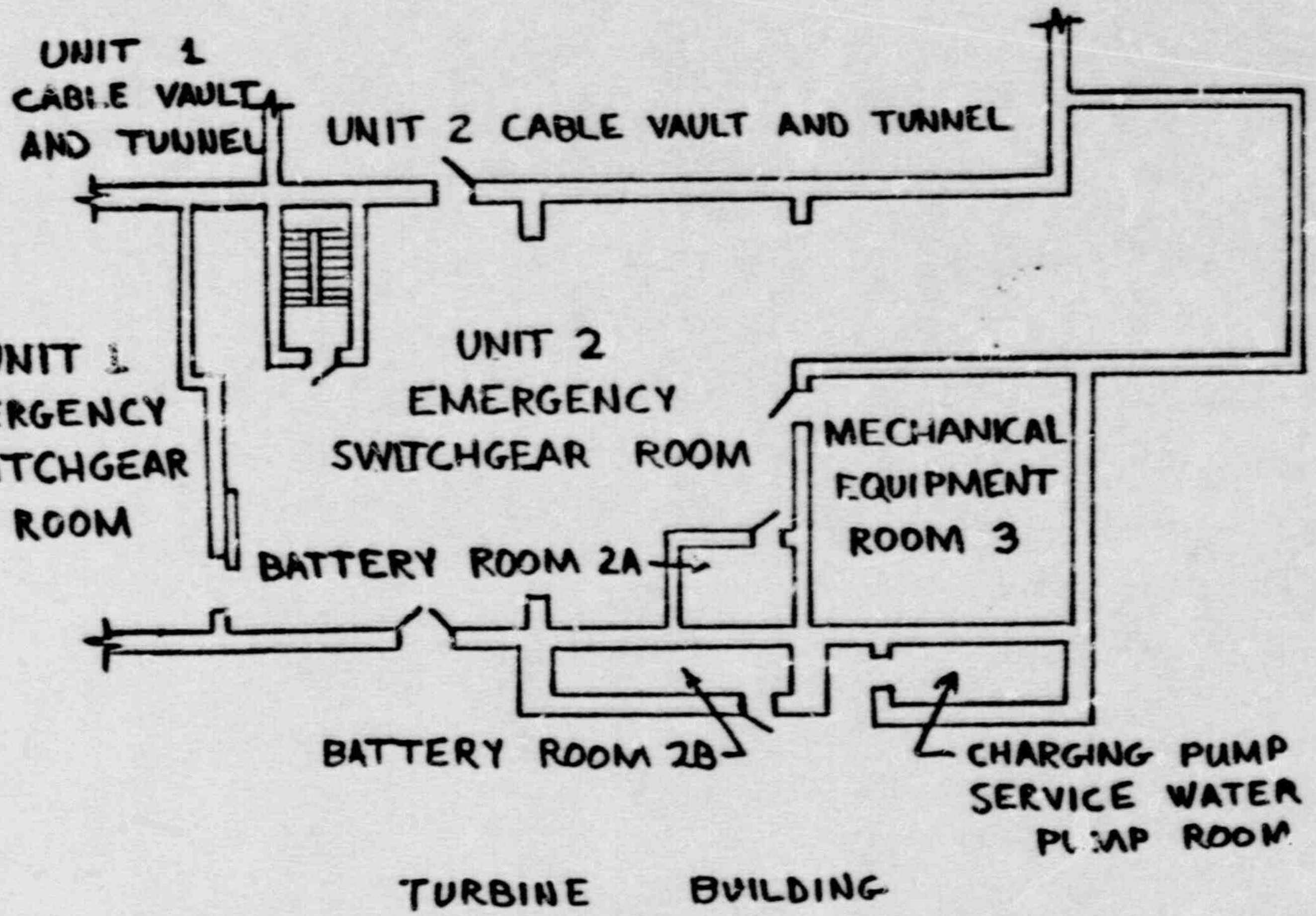


Figure 12 Unit 2 Emergency Switchgear Room (Fire Area 4)

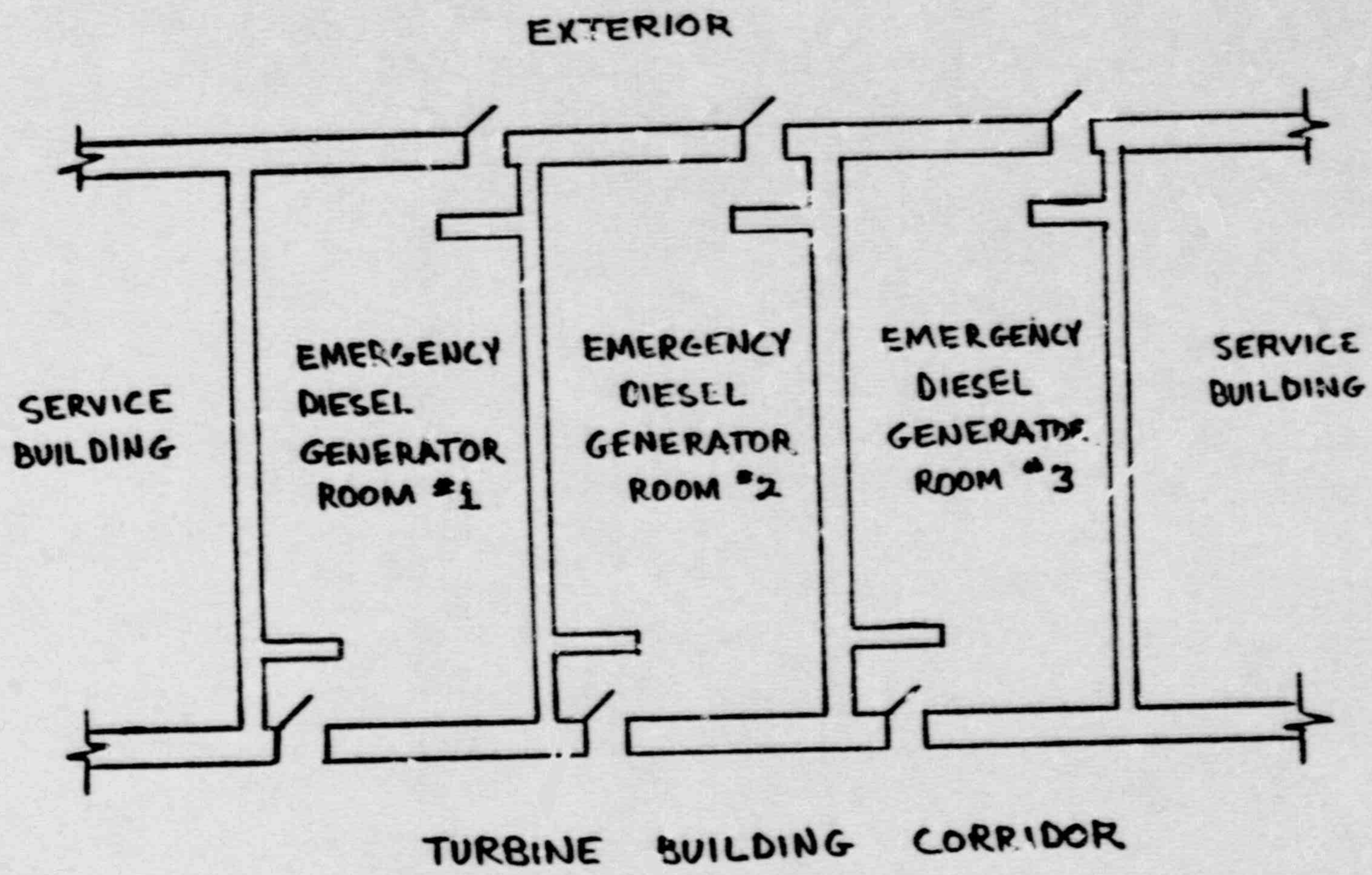


Figure 13 Emergency Diesel Generator Rooms

(Fire Areas 6, 7, and 8)

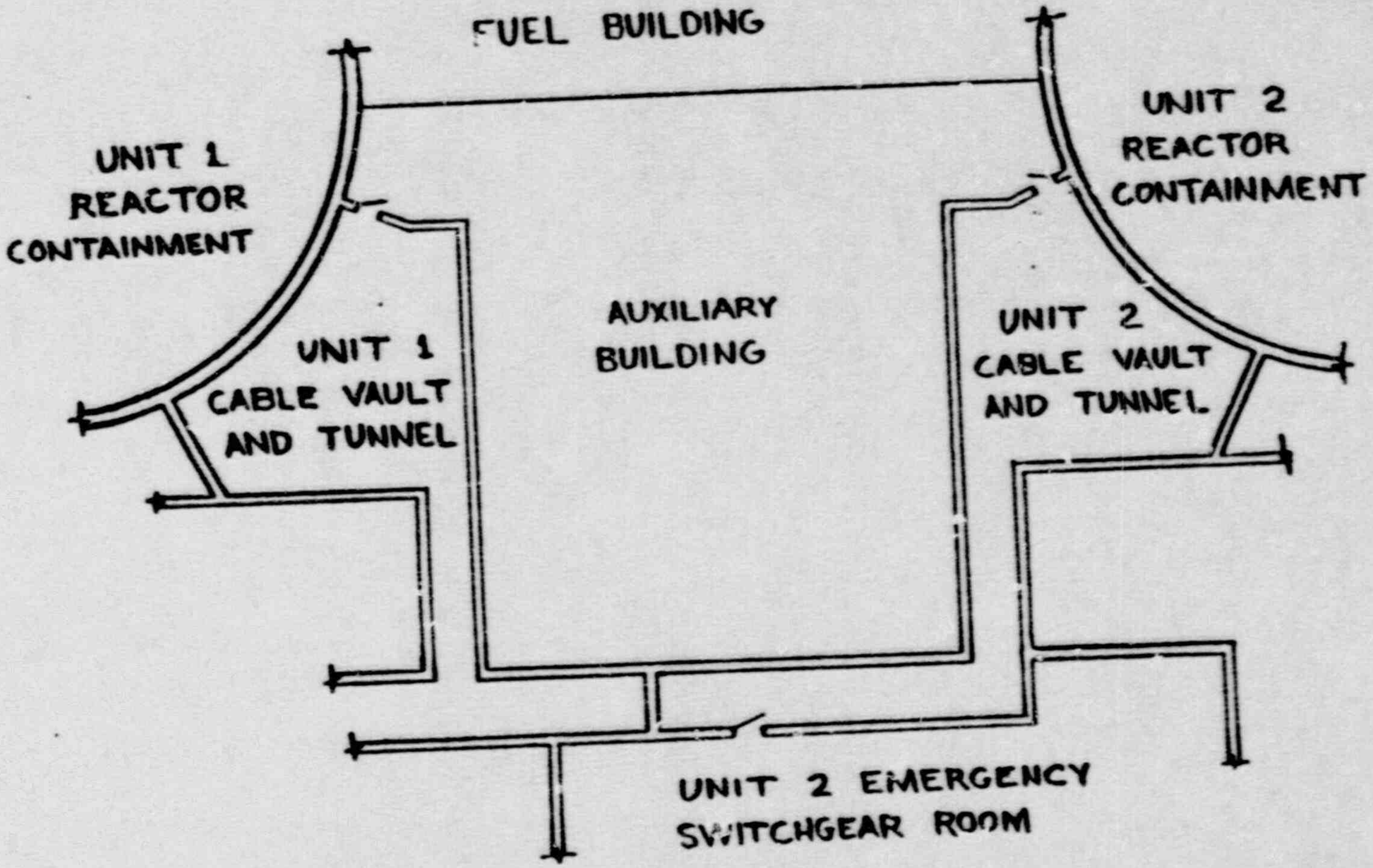


Figure 14 Auxiliary Building (Fire Area 17)

Table 10

Plant Fire Area Penetration

FIRE AREA	PENETRATION	CONNECTED AREAS
FA-1 (Unit 1 Cable Vault and Tunnel)	Doors	FA-3, FA-17
	Cables	FA-2, FA-3, FA-5, FA-17, FA-19,
FA-2 (Unit 2 Cable Vault and Tunnel)	Doors	FA-4, FA-17
	Cables	FA-1, FA-4, FA-5, FA-17, FA-20,
FA-3 (Unit 1 Emerg. Switchgear Room)	Doors	FA-1, FA-4
	Cables	FA-1, FA-5, FA-4, FA-31
FA-4 (Unit 2 Emerg. Switchgear Room)	Doors	FA-2, FA-3, FA-5, FA-31, FA-45
	Cables	FA-2, FA-3, FA-5, FA-31
FA-6 (Diesel Generator Room #1)	Doors	FA-31, Outside
	Cables	FA-7, FA-31
FA-8 (Diesel Generator Room #3)	Doors	FA-31, Outside
	Cables	FA-7, FA-31
FA-17 (Auxiliary Building)	Doors	FA-1, FA-2, FA-31, Outside
	Cables	FA-1, FA-2
FA-31 (Turbine Building)	Doors	FA-4, FA-5, FA-6, FA-8, FA-12, FA-17, FA-54, Outside
	Cables	FA-3, FA-4, FA-5, FA-6, FA-7, FA-8, FA-45, FA-46, FA-47

tree from which these are taken was shown in Figure 6. No possibility of a LOSP transient or LOCA caused directly by the fire itself or random causes alone was considered to be credible. Table 11 summarizes the transient sequences analyzed.

Sequences 1, 2, 3, 2B, and 3B are transients due to either a manual or automatic SCRAM in which both the auxiliary feedwater system and the capability to perform the "feed and bleed" operation are failed (due to a combination of failures arising from the FSS system actuation and random failures) which thus leads to a core damage situation since no primary system heat removal is possible.

Sequences 4 and 6 are small LOCA's caused either by failures of the reactor coolant pump seals or by failure of the pressurizer safety relief valves (PORVs) to reclose, resulting in loss of primary coolant inventory. In these sequences, the high pressure injection system is also failed, which leads to a core damage situation.

Sequences 7, 4B, 5B, 6B, and 7B are also small LOCA's as described above, but here the HPI is successful while there are failures of the low pressure injection and recirculation systems which lead to (late) core damage.

These sequences were analyzed for their applicability to the inadvertent FSS actuation root cause scenarios as described in Chapter 3.0. The criteria used were listed in Table 6. These criteria were applied to each cutset in the vital area analysis core damage sequences which were developed in the fire PRA performed as part of the NUREG 1150 program. In this process, many cutsets and several sequences were screened out from further consideration.

The sequences and cutsets that remained were grouped according to the ten root causes described above. These sequences and cutsets are listed in Appendix B and are discussed in Section 4.2.3. Note that root cause 7 was eliminated from further consideration since the plant under consideration does not use any smoke detectors to actuate its automatic suppression systems.

4.2.2 LOSP Transients Due To Seismic Events

The transient event tree associated with loss of offsite power used for this study is given in Figure 7. A total of six sequences leading to core damage are given on this tree, and these sequences are listed on Table 12. Sequence T_1-1 is a seal LOCA which arises due to simultaneous failure of the HPI (D_3) and the CCW (W) systems. Since early injection cooling is failed (D_1), a core damage situation results. Sequence T_1-3 is a loss of offsite power transient in which the AFWS system has failed, early injection and high pressure recirculation have succeeded, but low pressure recirculation (H_2) has failed. Thus, this is a late core damage sequence. Sequence T_1-4 is similar except that, in this

TABLE 11

General Transient Accident Sequences Analyzed

Sequence 1	$T_3*D_3*L*\overline{W}*M$	
Sequence 2	$T_3*\overline{D_3}*L*M*D_2$	
Sequence 3	$T_3*\overline{D_3}*L*M*\overline{D_2}*P$	
Sequence 4	$T_3*D_3*W*D_1$	(Seal LOCA)
Sequence 6	T_3*Q*D_1	(Stuck open relief valve)
Sequence 7	$T_3*\overline{Q}*\overline{D_1}*L*P_1$	" "
Sequence 2B	$T_3*\overline{D_3}*L*M*\overline{D_2}*P*H_1$	
Sequence 3B	$T_3*\overline{D_3}*L*M*\overline{D_2}*P*H_2$	
Sequence 4B	$T_3*\overline{Q}*\overline{D_1}*L*\overline{P_1}*H_1$	
Sequence 5B	$T_3*\overline{Q}*\overline{D_1}*L*\overline{P_1}*H_2$	
Sequence 6B	$T_3*\overline{Q}*\overline{D_1}*\overline{L}*H_1$	
Sequence 7B	$T_3*\overline{D_1}*\overline{L}*H_2$	

TABLE 11 (Cont'd)

Safety Systems Nomenclature

C	Containment spray system (CSS)
D_1	High pressure injection (HPI)
D_2	Same as HPI
D_3	High pressure injection for seal cooling
D_5	Accumulators (ACC)
D_6	Low pressure injection (LPI)
F_1	Inside spray recirculation (ISR)
F_2	Outside spray recirculation (OSR)
H_1	Low pressure recirculation (LPR·LH)
H_2	Low pressure recirculation (LPR·HH)
L	Auxiliary feedwater system (AFWS)
M	Main feedwater (PCS)
OD	Operator depressurization (OD)
P_1	Block valves and PORV system (one valve required) (PPS2)
P	Block valves and PORV system (both valves required) (PPS1)
W	Component cooling water system (CCW)

TABLE 12

Loss of Off-Site Power Transient Sequences

$T_1\text{-}1 = T_1 * \bar{K} * \bar{Q} * \bar{L} * D_1 * D_3 * W$

$T_1\text{-}3 = T_1 * \bar{K} * \bar{Q} * L * \bar{D}_2 * \bar{P} * \bar{H}_1 * H_2$

$T_1\text{-}4 = T_1 * \bar{K} * \bar{Q} * L * \bar{D}_2 * \bar{P} * H_1$

$T_1\text{-}5 = T_1 * \bar{K} * \bar{Q} * L * \bar{D}_2 * P$

$T_1\text{-}6 = T_1 * \bar{K} * \bar{Q} * L * D_2$

case, failure of the high pressure recirculation system (H_1) has occurred. Sequence T_1-5 and sequence T_1-6 are both early core damage scenarios in which the AFWS has failed and the capability to perform feed and bleed has also been compromised. In the first case, both the PORVs or associated block valves have failed while, in the second case, the HPI system itself has failed. In both cases, no emergency core cooling is available and hence, an early core damage situation exists.

Since no vital area analysis had been performed for the LOSP sequences in the original PRA, one was performed as part of this study. The resulting accident sequences expressed in terms of fire zones and random failures are discussed in Section 4.2.3. In this process it was found that sequences T_1-3 and T_1-5 were negligible. The remaining three sequences were quantified for root causes 8 and 9 as described in Chapter 4.2.3.

4.2.3 Quantification

4.2.3.1 Quantification of Random and Fire-Induced Actuation Scenarios

Scoping quantification of the accident sequence frequencies was performed using the equations presented on Table 7 and discussed in Chapter 3.0 . Table 13 summarizes the fire frequencies used for each area. Table 14 summarizes the fire frequencies for several of the fire areas containing FSS systems due to fires occurring in any of the adjacent fire areas which could potentially cause inadvertent FSS actuation due to barrier failure. For this scoping study of a prototypical PWR, partitioning of the fire frequencies for the larger fire areas was not performed, since this is a highly plant specific aspect. The exact equations and specific values used for each sequence and each cutset are listed in tables given in Appendix B for each root cause, accident sequence, and each fire zone.

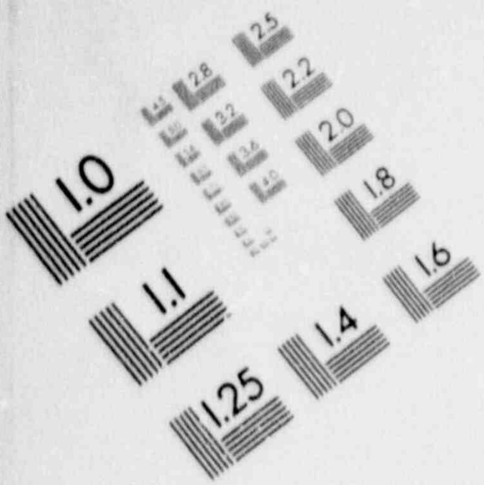
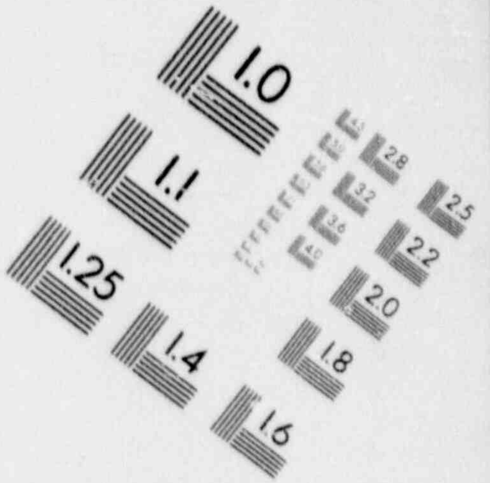
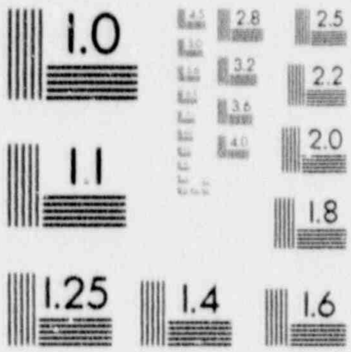
To illustrate the the format used in these tables, consider the entry for Sequence 4, Root Cause 1, Fire Zone 1 which is repeated here from Appendix B .

```
1    1.0000e+00     FRZ-1 *
                    P(fire in 5 or 17)= 6.83e-02;
                    P(fire next to 1 but not in 5 or 17)=2.33e-02;
FREQUENCY = [(6.83e-02) * (0.1) * (0.1) * (0.26)] +
            [(2.33e-02) * (0.1) * (0.1) * (4.4e-02)] = 1.88e-04
```

The first line gives the SETS code cutset index (1) followed by the screening value of the cutset (1.00e+00), and then the cutset itself (FRZ-1). This indicates that the cutset is a single, ie., inadvertant

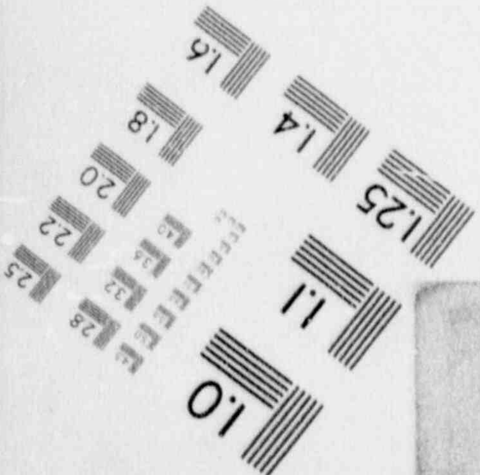
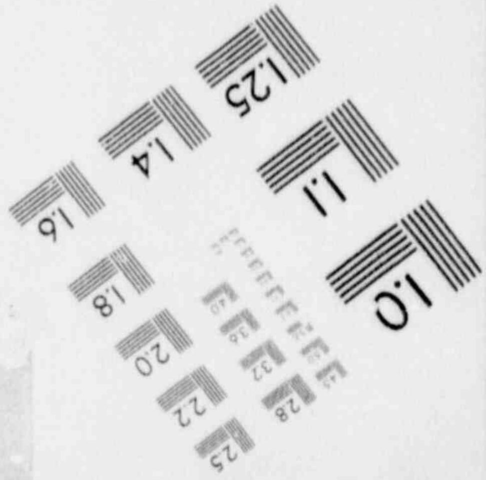
1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

1

**IMAGE EVALUATION
TEST TARGET (MT-3)**

150mm

6"

1

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6″

Table 13

Fire Frequencies Corresponding For Plant Fire Areas

FIRE AREA	FIRE FREQUENCY
Cable Vault and Tunnel (Fire areas 1 and 2)	2.68 E-03
Emergency Switchgear Room (Fire areas 3 and 4)	2.97 E-03
Control Room (Fire area 5)	4.40 E-03
Emergency Diesel Generator Room (Fire areas 6, 7, and 8)	2.31 E-02
Reactor Building (Fire areas 15 and 16)	1.77 E-02
Auxiliary Building (Fire area 17)	6.38 E-02
Safeguards Area (Fire areas 19 and 20)	1.77 E-02
Turbine Building (Fire area 31)	3.21 E-02
Mechanical Equipment Room #3 (Fire area 45)	3.71 E-03
Charging Pump Service Water Pump Room (Fire area 54)	3.71 E-03

Table 14

Fire Frequencies in Adjacent Areas

FIRE AREA OF INTEREST

	FA-1		FA-2		FA-3	
ADJACENT AREAS	FA-2	2.68E-03	FA-1	2.68E-03	FA-1	2.68E-03
	FA-3	2.97E-03	FA-4	2.97E-03	FA-4	2.97E-03
	FA-5	4.40E-03	FA-5	4.40E-03	FA-5	4.40E-03
	FA-17	6.39E-02	FA-17	6.39E-02	FA-31	3.21E-02
	FA-19	1.77E-02	FA-20	1.77E-02		
		9.16E-02		9.16E-02		4.21E-02

FIRE AREA OF INTEREST

	FA-4		FA-17		FA-31	
ADJACENT AREAS	FA-2	2.68E-03	FA-1	2.68E-03	FA-3	2.97E-03
	FA-3	2.97E-03	FA-2	2.68E-03	FA-4	2.97E-03
	FA-5	4.40E-03	FA-31	3.21E-02	FA-5	4.40E-03
	FA-31	3.21E-02			FA-6	2.31E-02
	FA-45	3.71E-03			FA-7	2.31E-02
					FA-8	2.31E-02
		4.59E-02		3.75E-02	FA-12	2.97E-03
					FA-17	6.39E-02
					FA-45	3.71E-03
					FA-54	3.71E-03
						1.54E-01

FIRE AREA OF INTEREST

	FA-6		FA-8	
ADJACENT AREAS	FA-7	2.31E-02	FA-7	2.31E-02
	FA-31	3.21E-02	FA-31	3.21E-02
		5.52E-02		5.52E-02

actuation of the FSS in fire zone 1 would, in and of itself, cause core damage if all equipment in the zone is failed. The following lines then quantify the cutset. Lines 2 and 3 give the frequency of fires in zones connected to zone 1 (zones 2, 3, 5, 17, 19) taken from Table 10. The fire frequencies are taken directly from Table 13. Zones 5 and 17 are treated separately from the other interconnected zones because a "high stress factor" was applied to the recovery as described below and in Section 3.4.5. Line 4 uses the appropriate equation for Root Cause 1 from Table 7 to quantify the cutset. This is:

$$\phi_{cm} = \text{frequency(fire in any adjacent area)}*P(\text{barrier failure}) * P(\text{damage})*P(\text{random})*P(\text{recovery})$$

In this case there is no random failure in the cutset since the cutset is a single. Probability of barrier failure and of the conditional probability of equipment damage are both taken as 0.1 as described in Sections 3.4.2 and 3.4.3. The probability of recovery associated with fires in zones 5 and 17 is 0.26 which incorporates a high stress factor as obtained from the original PRA. The probability of recovery associated with fires in zones 2, 3, and 19 is 4.4E-2, again taken from the original PRA. Thus lines 4 and 5 give the final result of 1.88E-4 for the frequency of this particular cutset arising due to Root Cause 1.

As a second example, consider Sequence 3, Root Cause 5, Fire zone 4 which is also reproduced from Appendix B below.

```
1.2000e-02   FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +   STEAM IN 31
1.2000e-02   FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +   STEAM IN 31
1.0000e-03   FRZ-4 * PPS-SOV-FT1456X +                     STEAM IN 31
1.0000e-03   FRZ-4 * PPS-SOV-FT1455CX +                    STEAM IN 31
6.0000e-04   FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +  STEAM IN 31
6.0000e-04   FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +  STEAM IN 31
9.0000e-05   FRZ-4 * DCP-BDC-STBUS1AX +                    STEAM IN 31
9.0000e-05   FRZ-4 * DCP-BDC-STBUS1BX +                    STEAM IN 31
7.0000e-05   FRZ-4 * PPS-CCF-FTPORVX +                     STEAM IN 31
2.7000e-05   FRZ-4 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +  STEAM IN 31
2.7000e-05   FRZ-4 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +    STEAM IN 31
2.7000e-05   FRZ-4 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +  STEAM IN 31
2.7000e-05   FRZ-4 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +  STEAM IN 31
2.7000e-05   FRZ-4 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +  STEAM IN 31
2.7000e-05   FRZ-4 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +    STEAM IN 31
1.2000e-05   FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +   STEAM IN 31
1.2000e-05   FRZ-4 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +    STEAM IN 31
1.2000e-05   FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +   STEAM IN 31
1.2000e-05   FRZ-4 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +    STEAM IN 31
-----------
2.7660e-02
FREQUENCY = (0.003) * (0.1) * (0.1) * (2.766e-02) * M = 3.32e-09
```

Here there are 19 cutsets involving fire zone 4 in conjunction with one or more random failures which lead to core damage. In this case, the equation for Root Cause 5 from table 7 is used:

$$\phi_{cm} = \text{frequency(steam pipe break)*P(barrier failure)}$$
$$\text{*P(equipment damage)*P(random failures)}$$

where the pipe break frequency is given in Section 3.4.7 as 0.003, the barrier failure and conditional equipment damage probabilities are both taken as 0.1 as given in Sections 3.4.2 and 3.4.3, and the probability of random failures is the sum of all the random failures shown, as taken from the original PRA. Finally, note that the term "M" was appended to each cutset. This represents failure of the Power Conversion System (PCS) and is required for this sequence as shown on Table 11. Since, in the original PRA, no Boolean expression was developed for the PCS, the failure of the PCS was treated as a constant and not included specifically in the vital area analysis. Hence it had to be manually added at this stage. Numerically, the value of M from the original PRA was 4.0E-3. Thus the last line gives the frequency of core damage due to Root Cause 5, accident sequence 3, fire zone 4 as 3.32E-9 per year.

4.2.3.2 Quantification of Seismically-induced FSS Actuations

As mentioned earlier, a vital area analysis for LOSP sequences did not previously exist for the plant under consideration, so one had to be performed for this study. This was performed using the SETS computer code as described in Reference 5, using the same methods and basic plant systems models as were used in the original PRA. The five sequences analysed were shown on Table 12, and the vital area analysis showed that sequences T_1-3 and T_1-5 were negligible.

The remaining three conditional accident sequences which resulted from the vital area analysis for Root Cause 8 are :

$$T_1\text{-}1 = P(LOSP)*\overline{K}*\overline{Q}*P(\text{equipment damage})$$
$$*\left[FZ\text{-}17 + FZ\text{-}31*P(72)\right]$$

$$T_1\text{-}4 = P(LOSP)*\overline{K}*\overline{Q}*P(\text{equipment damage})$$
$$*\left[FZ\text{-}4*P(73) + FZ\text{-}2*P(73)\right]$$

$$T_1\text{-}6 = P(LOSP)*\overline{K}*\overline{Q}*P(\text{equipment damage})*FZ\text{-}4$$

The sequences which resulted from the vital area analysis for Root Cause 9 are:

$$T_1\text{-}1 = P(LOSP)*\bar{K}*\bar{Q}*P(\text{equipment damage}) * \left[FZ\text{-}17 + FZ\text{-}31*P(72)\right]$$

$$T_1\text{-}4 = P(LOSP)*\bar{K}*\bar{Q}*P(\text{equipment damage}) * \left[FZ\text{-}4*P(73) + FZ\text{-}2*P(73)\right]$$

$$T_1\text{-}6 = P(LOSP)*\bar{K}*\bar{Q}*P(\text{equipment damage}) * \left[FZ\text{-}1 + FZ\text{-}3 + FZ\text{-}4*FZ\text{-}17 + FZ\text{-}4*FZ\text{-}31 + FZ\text{-}31*P(74) + FZ\text{-}31*P(75) + FZ\text{-}31*P(76)\right]$$

These sequences are simpler than those for random or fire-induced inadvertent FSS actuations because, since loss of offsite is assumed given in these sequences, considerably fewer failures are required to cause core damage.

The terms $\bar{K}$ and $\bar{Q}$ denote success of the reactor protection system and successful opening of the PORVs, and were taken as 1.0 consistent with the original PRA. P(LOSP) is the probability of loss of offsite power at any given peak ground acceleration level. The fragility for this event was taken from the original PRA.

The terms P(72) and P(73) denote human errors in failing to recover the low pressure recirculation and AC power system. Both of these events were set to 1.0 since no credit was taken for human recovery actions after the earthquake. The terms P(74), P(75), and P(76) are random failures of the turbine-driven auxiliary feedwater pump (failure to run, failure to start, and maintenance unavailibility, respectively). The corresponding numerical values are 0.120, 0.011, and 0.010 as taken from the original PRA.

The term P(equipment damage) is the conditional probability of damage to critical equipment given inadvertent actuation of the FSSs. As discussed in Section 3.4.2, the value of 0.1 was used for all types of equipment and all types of FSSs.

The terms FZ-1, FZ-2, FZ-3, FZ-4, FZ-17, and FZ-31 are the conditional probabilities of actuation of the FSSs in those particular fire zones. Depending on the root cause being considered, they were assigned either the fragility for relay chatter (root cause 8) or for seismically-induced failure of the FSS itself as discussed in Section 3.5.

The expressions for the accident sequences above are a function of peak ground acceleration, and hence must finally be integrated over the hazard curve for the plant site as discussed in Section 3.5. Note that in evaluating these accident sequences, the seismically-induced actuations of the FSSs were assumed to be fully correlated as described in Section 3.5, and hence the contributions of the different fire zones to each accident sequence are not independent and are not additive. Hence in presenting the final results, the contributions due to the individual fire zones cannot be explicitly separated as was done for the random and fire-induced actuation cases. However, from the structure of the accident sequences above it can be seen that each of these fire zones contribute nearly equally.

4.3 Results of Scoping Quantification

The results of the scoping quantification for the fire and random failure induced root causes are presented in Tables 15 through 21.

4.3.1 Root Cause 1 Fire-induced FSS Actuation Due To Smoke Spread

An increment of core damage frequency of 2.2 E-6/Rx-year was estimated for this root cause. Almost all of this contribution was due to sequence 4 which is a seal LOCA due to simultaneous failure of the HPI and CCW systems, which simultaneously causes the seal LOCA and fail early emergency coolant injection. The main contributing fire zones are the Unit 1 cable vault/tunnel and the emergency switchgear rooms. In these areas, there is sufficient equipment which (if failed) results in failure of both the HPI and the CCW systems.

4.3.2 Root Cause 2 Fire-induced FSS Actuation Preventing Recovery

For this root cause, an increment in core damage frequency of 2.6 E-6/Rx-year was computed. In this case, it is sequence 1 which is the major contributor, due to the high fire frequency in the Turbine building (FZ-31). This number represents a conservative scoping value, since the probability of non-recovery of the random failures was taken as 1.0 in all cases.

4.3.3 Root Cause 3 Fire-induced FSS Actuation Preventing Fire-fighting Access

This root cause of inadvertent fire suppression actuation was found not to be applicable to this PWR. It was found that those fires occurring in

Table 15

Frequencies for FSS Root Cause 1

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		3.19E-09		1.28E-06				1.29E-06
2		2.90E-09		1.45E-09				4.35E-09
3		1.01E-07		5.08E-08				1.52E-07
4	1.88E-04		2.81E-05				1.65E-07	2.16E-04
6	4.58E-08		2.11E-08				1.88E-10	6.71E-08
7		1.91E-11		9.59E-12				2.87E-11
2-B		1.01E-07		5.08E-08				1.52E-07
3-B								
4-B		4.59E-08		2.30E-08				6.83E-08
5-B		6.55E-11		3.28E-11				9.83E-11
6-B								
7-B								
TOTALS	1.88E-04	2.54E-07	2.81E-05	1.41E-06			1.65E-07	2.18E-04

Table 16

Frequencies for FSS Root Cause 2

SEQUENCE	FIRE ZONE 1	2	3	4	31	45	54	TOTALS
1		9.33E-10		1.03E-09	1.82E-06		3.82E-10	1.82E-06
2		8.47E-10		9.39E-10				1.79E-09
3		2.97E-08		3.29E-08				6.26E-08
4					5.76E-07	2.99E-08	6.66E-08	6.73E-07
6						3.39E-11		3.39E-11
7		5.60E-12		6.21E-12				1.18E-11
2-B		2.97E-08		3.29E-08				6.26E-08
3-B								
4-B		1.34E-08		1.49E-08				2.83E-08
5-B		1.92E-11		2.12E-11				4.04E-11
6-B								
7-B								
TOTALS		7.46E-08		8.27E-08	2.40E-06	9.69E-08	6.70E-08	2.65E-06

Table 17

Frequencies for FSS Root Cause 4

SEQ.	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.39E-09		1.39E-09				2.78E-09
2		1.26E-09		1.26E-09				2.53E-09
3		4.43E-08		4.44E-08		9.20E-11		8.87E-08
4	1.76E-05		1.76E-05		2.03E-08	2.03E-08	1.76E-07	3.54E-05
6	2.00E-08		2.00E-08		2.31E-11	2.31E-11	2.00E-10	4.02E-08
7		8.36E-12		8.36E-12				1.67E-11
2-B		4.43E-08		4.44E-08		9.20E-11		8.87E-08
3-B								
4-B		2.00E-08		2.00E-08				4.01E-08
5-B		2.86E-11		2.86E-11				5.72E-11
6-B								
7-B								
TOTALS	1.76E-05	1.11E-07	1.76E-05	1.11E-07	2.04E-08	2.05E-08	1.76E-07	3.57E-05

Table 18

Frequencies for FSS Root Cause 5

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.04E-10		1.04E-10				2.08E-10
2		9.48E-11		9.48E-11				1.90E-10
3		3.32E-09		3.32E-09	5.20E-13	5.20E-13		6.64E-09
4	3.00E-05				1.32E-10	1.32E-10	3.00E-06	3.30E-05
6	1.50E-09				1.50E-13	1.50E-13	1.50E-10	1.65E-09
7		6.27E-13		6.27E-13				1.25E-12
2-B		3.32E-09		3.32E-09	5.20E-13	5.20E-13		6.64E-09
3-B								
4-B		1.50E-09		1.50E-09				3.00E-09
5-B		2.15E-12		2.15E-12				4.29E-12
6-B								
7-B								
TOTAL	3.00E-05	8.34E-09		8.35E-09	1.33E-10	1.33E-10	3.00E-06	3.30E-05

Table 19

Frequencies for FSS Root Cause 6

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.74E-09		1.67E-10				1.91E-09
2		1.58E-09		1.52E-10				1.73E-09
3		5.53E-08		5.31E-09				6.06E-08
4	2.20E-05		2.11E-06				2.20E-07	2.43E-05
6	2.50E-08		2.40E-09				2.50E-10	2.77E-08
7		1.05E-11		1.00E-12				1.15E-11
2-B		5.53E-08		5.31E-09				6.06E-08
3-B								
4-B		2.50E-08		2.40E-09				2.74E-08
5-B		3.58E-11		3.43E-12				3.92E-11
6-B								
7-B								
TOTAL	2.20E-05	1.39E-07	2.11E-06	1.33E-08			2.20E-07	2.45E-05

Table 20

Frequencies For Root Cause 8

Accident Sequence		Frequency(per year)
T_1-1		3.3E-6
T_1-4		3.3E-6
T_1-6		1.8E-6
	Total	8.4E-6

Table 21

Frequencies For Root Cause 9

Accident Sequence		Frequency(per year)
T_1-1		2.1E-5
T_1-4		2.1E-5
T_1-6		2.4E-5
	Total	6.6E-5

areas from which smoke spread could activate the FSS in adjacent areas were fires which damaged the critical equipment in a time too quick for manual response and suppression to be effective (as shown in the original fire PRA). Hence this root cause was not quantified.

4.3.4 Root Cause 4 FSS Actuation Caused By Human Error

Here, an increment in core damage frequency of 3.6 E-5/Rx-year was computed. The dominant contributor was sequence 4 for the same reasons as given in section 4.3.1, failure of equipment in the Unit 1 cable vault/tunnel and emergency switchgear rooms. Note that the switchgear rooms utilize Halon only, so the contribution due to this fire zone is quite conservative. However, the Halon and CO_2 systems were assumed to have equal damage potential as they are both commonly used in similar applications at different plants.

4.3.5 Root Cause 5 FSS Actuation Caused By Pipe Break

The increment in core damage frequency for this root cause was estimated as 3.3 E-5. It again arises primarily due to inadvertent FSS actuations in the cable vault/tunnel giving rise to sequence 4 as described above. Here, these inadvertent actuations are caused by steam line breaks in the auxiliary building. All other sequences and fire zones are negligible contributors to core damage frequency.

4.3.6 Root Cause 6 FSS Actuation Caused By Random Failures In FSS

The increment in core damage frequency for this root cause was estimated as 2.5 E-5. It again arises primarily due to inadvertent FSS actuations in the cable vault/tunnel giving rise to sequence 4 as described above. All other sequences and fire zones are negligible.

4.3.7 Root Cause 7 Dust-Triggered FSS Actuations In Seismic Events

As noted earlier, the plant under consideration does not utilize automatic fire suppression systems which could be automatically actuated by dust raised during a seismic event. (Certain fire zones do have either ionization or smoke detectors, but they are not used to activate any of the automatic fire suppression systems). Hence, this root cause could not be quantified for the plant under consideration.

4.3.8 Root Cause 8 Relay Chatter FSS Actuations In Seismic Events

The risk increment associated with this root cause was found to be 8.4 E-6 per Rx-year as shown on Table 20. Each of the three sequences contributed roughly equally, since each accident sequence involved fire areas containing automatic FSS systems which entered into the equations as (effectively) single events.

4.3.9 Root Cause 9 FSS Actuations Due To Seismic Failures Of FSS

The core damage increment associated with this root cause was found to be 6.6 E-5 per Rx-year as shown on Table 21. Again, each of the three non-negligible accident sequences contributed roughly equally. This core damage increment was computed based on an assumed fragility for the various FSS systems having a median failure level of 0.30g, which is twice the SSE for the plant under consideration. Due to the nature of the components of a typical fire suppression system (pipes, valves, small pressurized tanks and actuation controls) it is expected that this is a conservative estimate of the failure level of a typical FSS system. However, such systems are not (in general) seismically qualified (except fire water standpipes inside the plant), and without a detailed evaluation of the specific system configurations, it is not possible to refine this assumption.

4.3.10 Root Cause 10 External Plant Fires Causing FSS Actuations

As noted earlier, in the timespan and within the resources available, it was not possible to identify the various paths that smoke from a fire external to the plant could follow into the plant, nor was it possible to identify the connectivity of the ventilation systems within the plant. Discussions with plant personnel indicated that approximately one hundred plant drawings would have to be obtained and studied to resolve questions raised for this root cause.

It should be noted, however, that this PWR site does have a fairly thick wooded area in close proximity to the reactor buildings, and that external fires are a real possibility. Only those FSSs activated by smoke detectors would be of concern, since it is not likely that room temperatures would be raised sufficiently by an off-site fire to activate heat detectors. A number of manually activated FSSs are alarmed with smoke detectors, which could be set off by an outside fire and cause the operators to activate the FSS system. Hence, inadvertent actuation due to offsite fires is a non-negligible possibility.

4.4 Summary

As described above, of the ten root cause scenarios postulated to lead to core damage resulting from inadvertent actuation of the prototypical power plant's fire suppression systems, two were found not to be applicable to the plant (FSS actuation preventing manual fire-fighting and FSS actuation due to dust raised in a seismic event) and one could not be analysed (smoke entering the plant from an outside fire) because the accessibility of the various fire zones via the plant ventilation systems could not be identified without a major review of plant drawings.

The seven remaining root cause scenarios led to a total increment in core damage frequency of 3.9E-4 per reactor year. The dominant contributor to this total was Root Cause 1 which was due to smoke spreading into either the Unit 1 cable vault/tunnel or Emergency Swithgear rooms from fires in surrounding rooms. These scenarios contributed 2.3E-4 to the total. Root Cause 2 (FSS actuation preventing access for manual recovery actions) contributed only 2.6E-6 to the total and thus was only a minor contributor at this plant. Core damage due to FSS actuations due to (a) human errors, (b) steam pipe break, and (c) random FSS failures each contributed approximately 3E-5 to the total and thus were relatively significant contributors. Finally, of the two seismic causes analysed, FSS actuation due to relay chatter was a very significant contributor (6.6E-5) to the total, while FSS actuations due to seismically-induced failures of the FSS system itself contributed only 8.4E-6 to the total.

5.0 SENSITIVITY STUDIES

The above results represent a base case analysis that uses the parameter values presented in section 3.4. As discussed there, several of the parameter values are thought to be conservative estimates. In particular, the values taken for the probability of equipment damage from the FSS actuation and for the probability of barrier failure were chosen on the conservative side due to lack of data. This section describes sensitivity studies in which three of the more uncertain estimates are varied (ie., the probability of Halon damage to equipment, the probability of FSS damage to cables, and the probability of barrier failure). Table 22 summarizes the results of these studies. Descriptions of each sensitivity study are presented below.

5.1 Sensitivity Study 1 - Decrease in Equipment Damage from Halon

For the base case analysis, an inadvertent Halon system actuation was assumed to have a conditional probability of 0.1 of damaging nearby equipment. Nevertheless, as discussed in section 3.4.2 above, the detailed LER review found no reports of an inadvertent Halon release damaging plant equipment.

Moreover, the damage mechanism involved in the one reported case of CO_2-induced damage (i.e., an "overdump" of CO_2) is not plausible at the PWR plant under study because their Halon system uses a limited number of gas cylinders. Hence it can be argued that the possibility of equipment damage from a Halon system actuation should be ignored at this plant.

Consequently, for this sensitivity study, the probability of an inadvertent Halon system actuation damaging plant equipment was taken to be zero. All other numerical values were kept the same as in the base case. The accident sequence cutsets were requantified to determine a new value of the increment in core damage frequency. Since the only Halon systems at the plant under study are in the two emergency switchgear rooms, only the cutsets involving these rooms changed in value.

The requantified contributions to the core damage frequency are given on Tables 23-28. The reason that the total for Root Cause 5 did not change (and that only minor changes occurred in the totals for Root Causes 1 and 6) is that the major contributing fire zone for these root causes is the Unit 1 cable vault/tunnel. The cable vault/tunnel is not affected by changes in the Halon damageability estimate. The results also show that sequence 4 is still the major contributing accident sequence for these root causes.

Table 22 Summary of Sensitivity Results
In Terms of Core Damage Frequency

		Assumption			
Root Cause	Base Case	No Halon Damage	Reduced CO_2 Damage To Cable	Barrier Failure=.01	All Combined
1.	2.18E-4	1.88E-4	4.85E-5	2.18E-5	1.90E-6
2.	2.65E-6	2.62E-6	2.62E-6	2.62E-7	2.62E-7
3.	Not applicable to plant under consideration.				
4.	3.57E-5	1.79E-5	1.97E-5	6.00E-6	1.99E-6
5.	3.30E-5	3.3E-5	6.01E-6	3.57E-5	3.30E-6
6.	2.45E-5	2.24E-5	4.56E-6	2.45E-5	2.44E-6
7.	N/A	N/A	N/A	N/A	N/A
8.	8.3E-6	5.06E-6	6.96E-6	N/A	3.48E-6
9.	6.5E-5	5.21E-5	6.47E-5	N/A	2.60E-5
10.	Could not be calculated for plant under consideration.				
Total	3.9E-4				3.9E-5

Table 23

Frequencies for FSS Root Cause 1

Assuming No Halon Damage

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		3.19E-09		0.00E+00				3.19E-09
2		2.90E-09		0.00E+00				2.90E-09
3		1.01E-07		0.00E+00				1.01E-07
4	1.88E-04		0.00E+00				1.65E-07	1.88E-04
6	4.58E-08		0.00E+00				1.88E-10	4.60E-08
7		1.91E-11		0.00E+00				1.91E-11
2-B		1.01E-07		0.00E+00				1.01E-07
3-B								
4-B		4.59E-08		0.00E+00				4.59E-08
5-B		6.55E-11		0.00E+00				6.55E-11
6-B								
7-B								
TOTALS	1.88E-04	2.54E-07	0.00E+00	0.00E+00			1.65E-07	1.88E-04

Table 24

Frequencies for FSS Root Cause 4

Assuming No Halon Damage

SEQ.	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.39E-09		0.00E+00				1.39E-09
2		1.26E-09		0.00E+00				1.26E-09
3		4.43E-08		0.00E+00		1.03E-10		4.44E-08
4	1.76E-05		0.00E+00		2.03E-08	2.03E-08	1.76E-07	1.78E-05
6	2.00E-08		0.00E+00		2.31E-11	2.31E-11	2.00E-10	2.02E-08
7		8.36E-12		0.00E+00				8.36E-12
2-B		4.43E-08		0.00E+00		1.03E-10		4.44E-08
3-B								
4-B		2.00E-08		0.00E+00				2.00E-08
5-B		2.86E-11		0.00E+00				2.86E-11
6-B								
7-B								
TOTALS	1.76E-05	1.11E-07	0.00E+00	0.00E+00	2.04E-08	2.06E-08	1.76E-07	1.79E-05

Table 25

Frequencies for FSS Root Cause 5

Assuming No Halon Damage

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.04E-10		0.00E+00				1.04E-10
2		9.48E-11		0.00E+00				9.48E-11
3		3.32E-09		0.00E+00	0.00E+00	0.00E+00		3.32E-09
4	3.00E-05				1.32E-10	1.32E-10	3.00E-06	3.30E-05
6	1.50E-09				1.50E-13	1.50E-13	1.50E-10	1.65E-09
7		6.27E-13		0.00E+00				6.27E-13
2-B		3.32E-09		0.00E+00	0.00E+00	0.00E+00		3.32E-09
3-B								
4-B		1.50E-09		0.00E+00				1.50E-09
5-B		2.15E-12		0.00E+00				2.15E-12
6-B								
7-B								
TOTALS	3.00E-05	8.34E-09		0.00E+00	1.32E-10	1.32E-10	3.00E-06	3.30E-05

Table 26

Frequencies for FSS Root Cause 6

Assuming No Halon Damage

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.74E-09		0.00E+00				1.74E-09
2		1.58E-09		0.00E+00				1.58E-09
3		5.53E-08		0.00E+00				5.53E-08
4	2.20E-05		0.00E+00				2.20E-07	2.22E-05
6	2.50E-08		0.00E+00				2.50E-10	2.53E-08
7		1.05E-11		0.00E+00				1.05E-11
2-B		5.53E-08		0.00E+00				5.53E-08
3-B								
4-B		2.50E-08		0.00E+00				2.50E-08
5-B		3.58E-11		0.00E+00				3.58E-11
6-B								
7-B								
TOTALS	2.20E-05	1.39E-07	0.00E+00	0.00E+00			2.20E-07	2.24E-05

Table 27

Frequencies For Root Cause 8
Assuming No Halon Damage

Accident Sequence	Frequency(per year)
T_1-1	3.3E-6
T_1-4	1.8E-6
T_1-6	0.0
Total	5.1E-6

Table 28

Frequencies For Root Cause 9
Assuming No Halon Damage

Accident Sequence	Frequency(per year)
T_1-1	2.1E-5
T_1-4	1.5E-5
T_1-6	1.5E-5
Total	5.1E-5

5.2 Sensitivity Study 2 - Decrease in Cable Damage from FSS Agents

In the base case analysis, an inadvertent FSS actuation was assumed to damage all active electro-mechanical equipment and cables with equal probability.

Cable damage is assumed to occur due to inadequate seals for the cables and the possibility of erroneous signals being generated in cables exposed to an overdump of CO_2. Although this has happened once in the past, it seems to be an unlikely event. The probability of FSS damage to cables was treated as a sensitivity issue. In this sensitivity study, the probability of FSS damage to cables was lowered from 0.1 to 0.01.

For the plant under study, this reduced probability affects only the two cable vault/tunnel areas. The reason is that all of the other fire areas contain (primarily) active electro-mechanical equipment for which the probability of damage was kept as 0.1. The two cable vault/tunnels (fire zones 1 and 2) contain mostly cables with a few motor control centers. Consequently, this sensitivity study was calculated assuming a probability of equipment damage from FSS actuation of 0.01 for fire zones 1 and 2, with all other zones remaining the same as in the base case.

The results of this study are summarized in tables 29-34. As in sensitivity study 1, the values for root cause 2 do not change and, therefore, are not repeated. The totals calculated for each root cause are seen to be generally much lower than those calculated for the first sensitivity study because the contribution from the Unit 1 cable vault/tunnel has been substantially decreased. When compared to the base case, the Unit 1 emergency switchgear room now assumes more importance in root causes 1, 4, and 6, and the auxiliary building becomes more important to root cause 5. Note, however, that accident sequence 4 remains the dominant sequence.

5.3 Sensitivity Study 3 - Decrease in Barrier Failure Probability

For the base case quantification, the probability of failure of the barriers between two fire areas was taken to be 0.1. Since the probability of barrier failure to smoke or steam may be much less than the probability of barrier failure to fire, and since there may be only a few barriers per fire zone, the actual barrier failure probability may be less than 0.1. Hence, for this third sensitivity study, the barrier failure probability was taken to be 0.01 for all fire areas.

The requantified increments in core damage frequency are presented in tables 35-37. Since root causes 4 and 6 do not depend on barrier failures, their values do not change in this case. For root causes 1 and 2, all of the values decrease an order of magnitude. This result is

Table 29

Frequencies for FSS Root Cause 1
With Reduced Damage in FRZ-1 and 2

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		3.19E-10		1.28E-06				1.28E-06
2		2.90E-10		1.45E-09				1.74E-09
3		1.01E-08		5.08E-08				6.09E-08
4	1.88E-05		2.81E-05				1.65E-07	4.71E-05
6	4.58E-09		2.11E-08				1.88E-10	2.59E-08
7		1.91E-12		9.59E-12				1.15E-11
2-B		1.01E-08		5.08E-08				6.09E-08
3-B								
4-B		4.59E-09		2.30E-08				2.76E-08
5-B		6.55E-12		3.28E-11				3.94E-11
6-B								
7-B								
TOTALS	1.88E-05	2.54E-08	2.81E-05	1.41E-06			1.65E-07	4.85E-05

Table 30

Frequencies for FSS Root Cause 4
With Reduced Damage in FRZ-1 and 2

	FIRE ZONE							
SEQ.	1	2	3	4	6	8	17	TOTALS
1		1.39E-10		1.39E-09				1.53E-09
2		1.26E-10		1.26E-09				1.39E-09
3		4.43E-09		4.44E-08		9.20E-11		4.89E-08
4	1.76E-06		1.76E-05		2.03E-08	2.03E-08	1.76E-07	1.96E-05
6	2.00E-09		2.00E-08		2.31E-11	2.31E-11	2.00E-10	2.22E-08
7		8.36E-13		8.36E-12				9.20E-12
2-B		4.43E-09		4.44E-08		9.20E-11		4.89E-08
3-B								
4-B		2.00E-09		2.00E-08				2.20E-08
5-B		2.86E-12		2.86E-11				3.15E-11
6-B								
7-B								
TOTALS	1.76E-06	1.11E-08	1.76E-05	1.11E-07	2.04E-08	2.05E-08	1.76E-07	1.97E-05

Table 31

Frequencies for FSS Root Cause 5
With Reduced Damage in FRZ-1 and 2

	FIRE ZONE							
SEQUENCE	1	2	3	4	6	8	17	TOTALS
1		1.04E-11		1.04E-10				1.14E-10
2		9.48E-12		9.48E-11				1.04E-10
3		3.32E-10		3.32E-09	5.20E-13	5.20E-13		3.65E-09
4	3.00E-06				1.32E-10	1.32E-10	3.00E-06	6.00E-06
6	1.50E-10				1.50E-13	1.50E-13	1.50E-10	3.00E-10
7		6.27E-14		6.27E-13				6.90E-13
2-B		3.32E-10		3.32E-09	5.20E-13	5.20E-13		3.65E-09
3-B								
4-B		1.50E-10		1.50E-09				1.65E-09
5-B		2.15E-13		2.15E-12				2.36E-12
6-B								
7-B								
TOTALS	3.00E-06	8.34E-10		8.35E-09	1.33E-10	1.33E-10	3.00E-06	6.01E-06

Table 32

Frequencies for FSS Root Cause 6
With Reduced Damage in FRZ-1 and 2

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.74E-10		1.67E-10				3.41E-10
2		1.58E-10		1.52E-10				3.10E-10
3		5.53E-09		5.31E-09				1.08E-08
4	2.20E-06		2.11E-06				2.20E-07	4.53E-06
6	2.50E-09		2.40E-09				2.50E-10	5.15E-09
7		1.05E-12		1.00E-12				2.05E-12
2-B		5.53E-09		5.31E-09				1.08E-08
3-B								
4-B		2.50E-09		2.40E-09				4.91E-09
5-B		3.58E-12		3.43E-12				7.01E-12
6-B								
7-B								
TOTALS	2.20E-06	1.39E-08	2.11E-06	1.33E-08			2.20E-07	4.56E-06

Table 33

Frequencies For Root Cause 8
With Reduced Damage in FRZ-1 and -2

Accident Sequence		Frequency (per year)
T_1-1		3.3E-6
T_1-4		1.9E-6
T_1-6		1.8E-6
	Total	7.0E-6

Table 34

Frequencies For Root Cause 9
With Reduced Damage in FRZ-1 and -2

Accident Sequence		Frequency (per year)
T_1-1		2.1E-5
T_1-4		1.5E-5
T_1-6		2.0E-5
	Total	5.6E-5

Table 35

Frequencies for FSS Root Cause 1
With Reduced Barrier Failure Probability

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		3.19E-10		1.28E-07				1.29E-07
2		2.90E-10		1.45E-10				4.35E-10
3		1.01E-08		5.08E-09				1.52E-08
4	1.88E-05		2.81E-06				1.65E-08	2.16E-05
6	4.58E-09		2.11E-09				1.88E-11	6.71E-09
7		1.91E-12		9.59E-13				2.87E-12
2-B		1.01E-08		5.08E-09				1.52E-08
3-B								
4-B		4.59E-09		2.30E-09				6.89E-09
5-B		6.55E-12		3.28E-12				9.83E-12
6-B								
7-B								
TOTALS	1.88E-05	2.54E-08	2.81E-06	1.41E-07			1.65E-08	2.18E-05

Table 36

Frequencies for FSS Root Cause 2
With Reduced Barrier Failure Probability

SEQUENCE	FIRE ZONE (where fire occurs) 1	2	3	4	31	45	54	TOTALS
1		9.33E-11		1.03E-10	1.82E-07		3.82E-11	1.82E-07
2		8.47E-11		9.39E-11				1.79E-10
3		2.97E-09		3.29E-09				6.26E-09
4					5.76E-08	1.19E-11	6.66E-09	6.43E-08
6						3.39E-12		3.39E-12
7		5.60E-13		6.21E-13				1.18E-12
2-B		2.97E-09		3.29E-09				6.26E-09
3-B								
4-B		1.34E-09		1.49E-09				2.83E-09
5-B		1.92E-12		2.12E-12				4.04E-12
6-B								
7-B								
TOTALS		7.46E-09		8.27E-09	2.40E-07	6.71E-09	6.70E-09	2.62E-07

Table 37

Frequencies for FSS Root Cause 5
With Reduced Barrier Failure Probability

	FIRE ZONE							
SEQUENCE	1	2	3	4	6	8	17	TOTALS
1		1.04E-11		1.04E-11				2.08E-11
2		9.48E-12		9.48E-12				1.90E-11
3		3.32E-10		3.32E-10	5.20E-15	5.20E-15		6.64E-10
4	3.00E-06				1.32E-12	1.32E-12	3.00E-06	6.00E-06
6	1.50E-10				1.50E-15	1.50E-15	1.50E-10	3.00E-10
7		6.27E-14		6.27E-14				1.25E-13
2-B		3.32E-10		3.32E-10	5.20E-15	5.20E-15		6.64E-10
3-B								
4-B		1.50E-10		1.50E-10				3.00E-10
5-B		2.15E-13		2.15E-13				4.29E-13
6-B								
7-B								
TOTALS	3.00E-06	8.34E-10		8.34E-10	1.33E-12	1.33E-12	3.00E-06	6.00E-06

due to all of the cutsets for these root causes requiring the failure of one barrier between two zones. The total increment for root cause 5 decreases from 3.3E-5 to 6.0E-6. The decrease for this root cause is less than an order of magnitude because it includes cutsets involving the auxiliary building that do not depend on barrier failures.

As in the base case, accident sequence 4 and the cable vault/tunnel are important to root cause 1, and sequence 1 and the turbine building are important to root cause 2. For root cause 5, however, the auxiliary building becomes more of a contributor than it was in the base case.

5.4 Sensitivity Study 4 - Combination of Studies 1, 2, and 3

For this final sensitivity study, all the changes mentioned in the three previous studies were incorporated simultaneously. Specifically, the FSS was presumed not to damage equipment in fire zones 3 and 4, the probability of FSS damage in fire zones 1 and 2 was taken to be 0.01, and the probability of barrier failure was assumed to be 0.01. The accident sequence cutsets were then requantified with all other values being kept the same as in the base case. Hence, this sensitivity study represents the most optimistic analysis--and the most optimistic results--in this report.

The resulting increments in core damage frequency are summarized in Tables 38-44. For root cause 1, the total increment has decreased from 2.2E-4 in the base case to 1.9E-6. Accident sequence 4 and fire zone 1 remain the major contributors as in the base case.

For root cause 2, the total increment decreases from 2.6E-6 to 2.6E-7, reflecting the order of magnitude change in the barrier failure probability. Sequence 1 and the turbine building are still the major contributors.

The total increment for root cause 4 decreases from 3.6E-5 in the base case to 2.0E-6 here. Sequence 4 and the cable vault/tunnel remain as the dominant contributors.

The total increment for root cause 5 decreases by an order of magnitude from the base case, going from 3.3E-5 to 3.3E-6. The dominant sequence is still sequence 4, but the main contributing area is now the auxiliary building since it is unaffected by any of the changed assumptions.

For root cause 6, the total increment decreases from 2.5E-5 to 2.4E-6. Sequence 4 and the cable vault/tunnel remain as the dominant contributors for this root cause.

Table 38

Frequencies for FSS Root Cause 1
Combined Sensitivity Study

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		3.19E-11		0.00E+00				3.19E-11
2		2.90E-11		0.00E+00				2.90E-11
3		1.01E-09		0.00E+00				1.01E-09
4	1.88E-06		0.00E+00				1.65E-08	1.90E-06
6	4.58E-10		0.00E+00				1.88E-11	4.77E-10
7		1.91E-13		0.00E+00				1.91E-13
2-B		1.01E-09		0.00E+00				1.01E-09
3-B								
4-B		4.59E-10		0.00E+00				4.59E-10
5-B		6.55E-13		0.00E+00				6.55E-13
6-B								
7-B								
TOTALS	1.88E-06	2.54E-09	0.00E+00	0.00E+00			1.65E-08	1.90E-06

Table 39

Frquencies for FSS Root Cause 2
Combined Sensitivity Study

SEQUENCE	FIRE ZONE (whure fire occurs) 1	2	3	4	31	45	54	TOTALS
1		9.33E-11		1.03E-10	1.82E-07		3.82E-11	1.82E-07
2		8.47E-11		9.39E-11				1.79E-10
3		2.97E-09		3.29E-09				6.26E-09
4					5.76E-08	1.19E-11	6.66E-09	6.43E-08
6						3.39E-12		3.39E-12
7		5.60E-13		6.21E-13				1.18E-12
2-B		2.97E-09		3.29E-04				6.26E-09
3-B								
4-B		1.34E-09		1.49E-09				2.83E-09
5-B		1.92E-12		2.12E-12				4.04E-12
6-B								
7-B								
TOTALS		7.46E-09		8.27E-09	2.40E-07	6.71E-09	6.70E-09	2.62E-07

Table 40
Frequencies for FSS Root Cause 4
Combined Sensitivity Study

SEQ.	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.39E-10		0.00E+00				1.39E-10
2		1.26E-10		0.00E+00				1.26E-10
3		4.43E-09		0.00E+00		1.03E-10		4.53E-09
4	1.76E-06		0.00E+00		2.03E-08	2.03E-08	1.76E-07	1.98E-06
6	2.00E-09		0.00E+00		2.31E-11	2.31E-11	2.00E-10	2.25E-09
7		8.36E-13		0.00E+00				8.36E-13
2-B		4.43E-09		0.00E+00		1.03E-10		4.53E-09
3-B								
4-B		2.00E-09		0.00E+00				2.00E-09
5-B		2.86E-12		0.00E+00				2.86E-12
6-B								
7-B								
TOTALS	1.76E-06	1.11E-08	0.00E+00	0.00E+00	2.04E-08	2.06E-08	1.76E-07	1.99E-06

Table 41

Frequencies for FSS Root Cause 5
Combined Sensitivity Study

SEQUENCE	FIRE ZONE 1	2	3	4	6	8	17	TOTALS
1		1.04E-12		0.00E+00				1.04E-12
2		9.48E-13		0.00E+00				9.48E-13
3		3.32E-11		0.00E+00	0.00E+00	0.00E+00		3.32E-11
4	3.00E-07				1.32E-12	1.32E-12	3.00E-06	3.30E-06
6	1.50E-11				1.50E-15	1.50E-15	1.50E-10	1.65E-10
7		6.27E-15		0.00E+00				6.27E-15
2-B		3.32E-11		0.00E+00	0.00E+00	0.00E+00		3.32E-11
3-B								
4-B		1.50E-11		0.00E+00				1.50E-11
5-B		2.15E-14		0.00E+00				2.15E-14
6-B								
7-B								
TOTALS	3.00E-07	8.34E-11		0.00E+00	1.32E-12	1.32E-12	3.00E-06	3.30E-06

Table 42

Frequencies for FSS Root Cause 6
Combined Sensitivity Study

	FIRE ZONE							
SEQUENCE	1	2	3	4	6	8	17	TOTALS
1		1.74E-10		0.00E+00				1.74E-10
2		1.58E-10		0.00E+00				1.58E-10
3		5.53E-09		0.00E+00				5.53E-09
4	2.20E-06		0.00E+00				2.20E-07	2.42E-06
6	2.50E-09		0.00E+00				2.50E-10	2.75E-09
7		1.05E-12		0.00E+00				1.05E-12
2-B		5.53E-09		0.00E+00				5.53E-09
3-B								
4-B		2.50E-09		0.00E+00				2.50E-09
5-B		3.58E-12		0.00E+00				3.58E-12
6-B								
7-B								
TOTALS	2.20E-06	1.39E-08	0.00E+00	0.00E+00			2.20E-07	2.44E-06

Table 43

Frequencies For Root Cause 8
Combined Sensitivity Study

Accident Sequence		Frequency(per year)
T_1-1		3.3E-6
T_1-4		1.8E-7
T_1-6		0.0
	Total	3.5E-6

Table 44

Frequencies For Root Cause 9
Combined Sensitivity Study

Accident Sequence		Frequency(per year)
T_1-1		2.1E-5
T_1-4		1.5E-6
T_1-6		3.4E-6
	Total	2.6E-5

The net result of this most optimistic analysis is to decrease the increments in core damage frequency about an order of magnitude, with the exception of root cause 1 which decreases about two orders of magnitude. In addition, while root cause 1 was the dominant root cause in the base case, now root causes 1, 4, 5, and 6 all have about the same total increment in core damage frequency.

5.5 Summary

The requantified contributions to core damage frequency are summarized on Table 22. As can be seen from this table, the impact of assuming no Halon damage to equipment was relatively minor for all root causes. (Note that the totals for Root Cause 2 did not change in any of the sensitivity studies since this root cause involves access prevention and not FSS damage.) The impact of reducing the conditional probability of CO_2 damage to cables was more significant, reducing some of the root cause sequence totals by an order of magnitude. Similarly, the impact of reducing the probability of barrier failure was up to an order of magnitude for some of the root cause totals.

Comparing the base care total incremental increase in core damage frequency due to inadvertent FSS actuations (3.9E-4 /Rx-yr) to the total for the combined sensitivity study case (3.9E-5 /Rx-yr) shows an order of magnitude decrease overall. Additional data for the uncertain parameters varied in these studies will be required to understand the true incremental increase in core damage frequency due to inadvertent FSS actuations.

6.0 COST/BENEFIT ASSESSMENT

In order to make a preliminary assessment of the cost-effectiveness (from a risk-averted viewpoint) of possible changes to the plant which would reduce or eliminate the risk increment due to inadvertent actuations of the fire suppression systems, the core damage frequency increments computed in Sections 4.0 and 5.0 were converted to off-site dose, possible plant modifications were identified (and their costs estimated), and a simple cost/benefit analysis was performed.

One measure of the benefit achieved in retrofitting a modification to a power plant (and which results in a decrease in public exposure due to an accident) is the Dollar-to-Man-REM Averted Ratio (DPR) as described in Reference 13. It can be computed including or excluding on-site costs. Including the onsite costs tends to make the benefit greater. As a first cut, one can neglect the on-site costs, and compute this ratio based only on off-site exposure. Thus, the ratio

$$DPR = \frac{\text{Cost of Modification}}{\text{Off-site man-REM averted}}$$

is used as the cost/benefit measure in this study.

In figuring the cost of modifications, in general, one should include costs due to replacement power during downtime, and costs associated with any additional future maintenance required. In figuring the averted dose, one should, in general, include dose experienced during the modification process. For this preliminary estimate, it is assumed that the modifications will be performed during a routine outage with negligible additional exposure. Further, it is assumed that no added maintenance costs will result due to the modifications. Thus the DPR cost/benefit ratio will be computed based only on the averted offsite man-REM dose and the estimated cost of the modification.

6.1 Offsite Dose Calculations

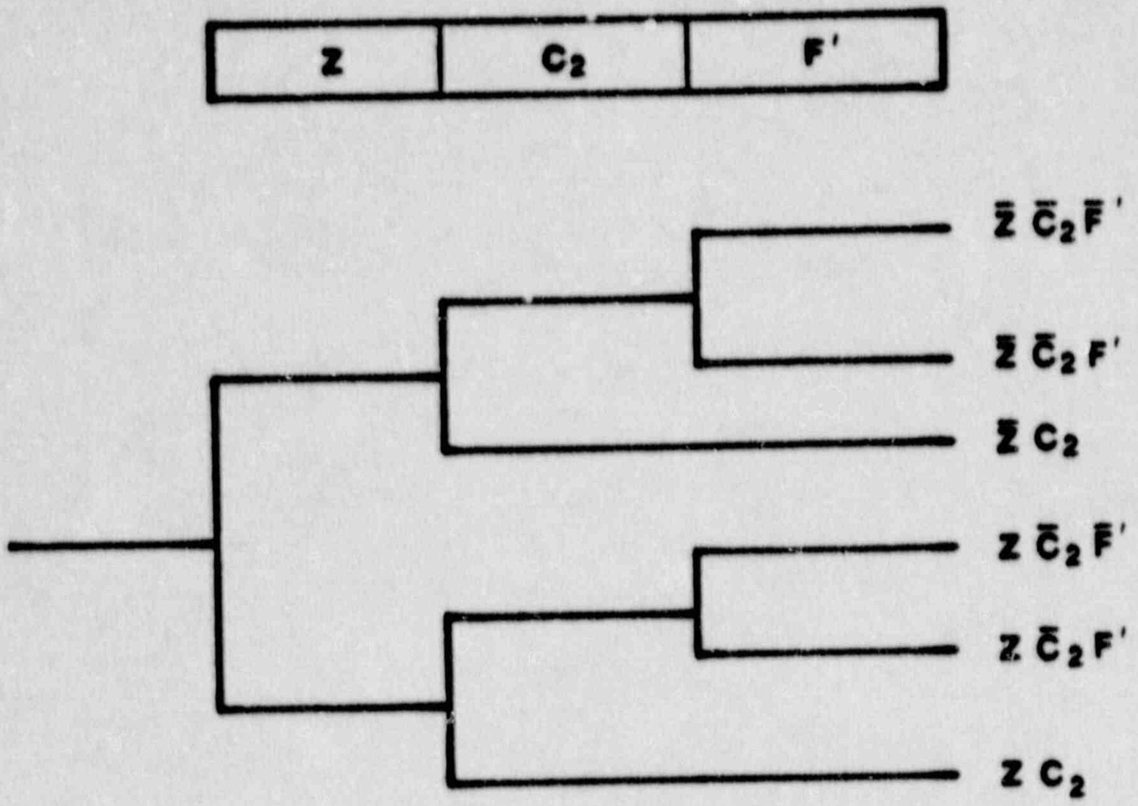
To convert the calculated core damage frequencies to offsite dose, a simple containment failure event tree (as was used in the WASH-1400 study, Reference 8) was used. The methodology used here is exactly the same as was used in the NRC-sponsored Adaquacy of Decay Heat Removal studies for Unresolved Safety Issue A-45 as reported in Reference 13. The generic PWR containment event tree (CET) is shown in Figure 15. Three containment functions are shown on this tree:

Z - Overpressure prevention function

C_2- Radiation removal function using sprays

F'- Radiation removal function using spray recirculation

Figure 15 Containment Event Tree



The tree shows six end states depending on the success or failure of the three functions above. Success or failure of the overpressure protection function is plant specific, but is a function of the status of the fan coolers, the containment spray pumps, and the containment spray recirculation pumps, depending on the success criteria for these systems for the specific plant under consideration. (Note that not all PWR plants have all three of these systems).

For the plant under consideration in this study, it was not necessary to determine the success criteria exactly, since for the fire zones under consideraton, only two end states are possible--ZC_2 in which all containment systems fail, and ZC_2F' in which none of the containment systems are failed. This follows from the fact that the cabling for all containment systems runs from the containment through the Safeguards area, control/vault tunnel and the Electrical Switchgear room and also (for control) to the control room. The only important fire zone found in this study that does not have cabling for the containment systems running through it is the Auxiliary building. Hence all cutsets for the above fire zones except the Auxiliary building are assumed to fail all containment systems because of damage to the cabling. Cutsets involving actuation of the FSS in the Auxiliary building are assumed to fail none of the containment systems. Thus only the "all fail" and the "no fail" branches on the containment event tree need be considered. (This is a very plant-specific result and is not to be expected in general).

This containment tree is used as follows. First, all cutsets in all sequences are mapped to one of the end state branches of the tree (in this case, the "all fail" or the "no fail" branches). From this, the frequencies of the different CET end state branches can be computed. These end states and their corresponding frequencies are then mapped to one of seven release categories (each release category corresponding to a specific containment failure mode with its own timing and mode of release of fission products as described in Reference 8). This mapping is performed with the split fractions and release category assignments shown on Table 45. Note that, for each CET branch shown on the left hand column of this table, the sum of the split fractions (shown horizontally to the right) equals to 1.0. Under each split fraction shown is the release category corresponding to that release fraction. Thus the frequency for each CET end state branch is split up and assigned to a specific release category.

Finslly, the frequencies of each release category are multiplied by a source term factor to obtain the offsite dose due to that containment failure mode. The source term factors were derived from more detailed

Table 45

PWR Accident Sequence To Release Category Mapping

Containment Systems Sequence	Special Conditions: Core Melt	Containment Failure Mode with Probability and Release Category: α	β	γ, δ_e	δ_t	ϵ
$\bar{Z}\bar{C}_2\bar{F}'$		1E-4 1	2E-3 5	1.4E-2 3	1.8E-1 5	2.5E-1 7
$\bar{Z}\bar{C}_2F'$	EM	1E-4 1	2E-3 5	1.4E-2 3	1.8E-1 4	2.5E-1 6
	LM	1E-4 1	2E-3 4	1.4E-2 2	1.8E-1 3	2.5E-1 6
$\bar{Z}C_2$		1E-4 1	2E-3 4	1.4E-2 2	1.8E-1 3	2.5E-1 6
$Z\bar{C}_2\bar{F}'$		1E-4 1	2E-3 5	1.4E-2 3	1.8E-1 5	2.5E-1 7
$Z\bar{C}_2F'$	EM	1E-4 1	2E-3 5	1.4E-2 3	1.8E-1 4	2.5E-1 6
	LM	1E-4 1	2E-3 4	1.4E-2 2	1.8E-1 3	2.5E-1 6
ZC_2		1E-4 1	2E-3 4	1.4E-2 2	1.8E-1 3	2.5E-1 6

* The exact definition of the containment sequence varies for the PWRs depending upon the system success criteria. See Appendix B, References 11 through 14.

EM ≡ early core melt, LM ≡ late core melt.

studies of containment failure and release and are used as generic estimates for a "typical" PWR as described in Reference 13. The source term factors used are shown below:

Release Category	Source Term
1	6.6E+5
2	7.5E+5
3	6.2E+5
4	2.7E+5
5	1.0E+5
6	2.2E+4
7	1.7E+3

Table 46 summarizes the dose (in terms of man-REM/year) for the base case and each of the sensitivity studies. It can be seen that the offsite population dose varied from a maximum of 821 man-REM/year for the base case down to 58 man-REM/year for the most optimistic of the sensitivity studies. These four sets of results are used to estimate cost/benefit measures below.

6.2 Potential Plant Modifications

Based on the dominant contributors to the increment in plant risk due to inadvertent actuation of the FSS systems, a number of potential plant modification were identified which could reduce (or eliminate) part of this risk increment. Five potential modifications were considered as shown on Table 47. Cost estimates for each of these modifications were based on Reference 14 and personal communication with plant fire protection personnel and commercial fire protection engineers. These cost estimates should be considered as rough estimates only, as such costs are very plant specific.

A. To replace the CO_2 system in the cable vault/tunnel with a Halon system. This is based on the fact that damage to cables in the cable vault/tunnel was seen to be a significant contributor in the base case. If we assume that Halon has significantly less potential of damaging cables given an inadvertent actuation, then a significant risk reduction would result. Estimated cost of this modification is in the $50-100K range.

Table 46
Summary of Base Case and Sensitivity Study Results
in Terms of Risk (man-REM/year)

Root Cause	Base Case	No Halon Damage	Reduced CO_2 Damage To Cable	Barrier Failure = 0.01	All Combined
1.	496.0	430.0	109.0	49.6	4.3
2.	3.4	3.4	3.4	0.3	0.3
3.	N/A	N/A	N/A	N/A	N/A
4.	81.1	40.6	44.8	81.0	4.3
5.	72.4	72.4	10.7	10.7	4.5
6.	55.6	50.7	10.2	55.6	5.3
7.	N/A	N/A	N/A	N/A	N/A
8.	10.8	6.5	9.0	N/A	4.5
9.	102.0	81.6	98.5	N/A	34.9
10.	N/A	N/A	N/A	N/A	N/A
TOTAL	821.3	685.2	285.6	197.2	58.1

Table 47

Possible Modifications & Costs

A. Replace CO_2 w/Halon system

Area affected - FZ1 Control Vault/Tunnel
Root Cause Scenario affected - all
Cost - $50 to $100K

B. Re-route one train of HPI & CCW Systems

Areas affected - FZ1, 3
Root Cause Scenario affected - all
Cost -

Thru adjacent area = $ 5-10K
Thru non-adjacent area = $10-50K

C. Replace CO_2/Halon Control Circuits w/Supervised printed circuit board control circuits

Area affected - FZ1, FZ3
Root cause scenario affected - RC8
Cost - $10K per system

D. Divide Fire Area by Physical Barrier Between Trains

Areas affected FZ3
Root cause scenarios affected - all
Cost - $100K (very approximate estimate)

E. Implement 24 hr Fire Watch in FZ-1, FZ-3

Cost = $640k/year

B. Re-route one train of cables from the Unit 1 cable vault/tunnel and emergency switchgear rooms to the corresponding Unit 2 rooms, which by virtue of the layout of this particular plant is a viable option according to plant personnel. This would prevent simultaneous failure of the HPI and CCW systems whose cables currently are in the same areas (although separated as required by Appendix R). This would reduce the impact of inadvertant FSS actuations on all root cause scenarios considered. The estimated cost of this modification is in the \$5-50K range depending on how the cables were to be re-routed (other factors could play a role in where the re-routing would be).

C. Replace the CO_2 and Halon systems control circuits with printed circuit boards to avoid relay chatter problems. This is already being done at a number of plants due to other considerations. The estimated cost is about \$10K per system.

D Erect physical barrier between trains of safety systems to prevent simultaneous failures due to FSS actuations in the Emergency Switchgear room. This would reduce the contribution of all scenarios, but would be very expensive. A very rough estimate would be \$100K. This was not quantified from a cost/benefit viewpoint because of the anticipated cost and the fact that, at this plant, the same risk reduction could be obtained with option A, all other things being equal.

E. An option which is always available is to post a permanent fire watch in crucial areas, in this case, the cable vault/tunnel and the Emergency Switchgear rooms. Using reasonable salary estimates and overhead rates, this option would cost at least \$640K per year. Given this cost and the fact that it would have to be implemented in both units, this option was not further considered.

It should be noted that the plant modifications identified above are likely to be those considered at any plant, with only the associated costs being significantly different.

6.3 Cost/Benefit Results

Using the risk estimates for the base case and the sensitivity studies from Table 46 and the cost estimates from Table 47, one can calculate the DPR ratio described earlier. Table 48 presents these ratios for the three most likely modifications (per plant year). Assuming a remaining plant life of 20 years, one has the following cost/benefit ratio values:

Modification A	4.6 to 9.2 dollars/man-REM
Modification B	0.3 to 3.0 dollars/man-REM
Modification C	231 dollars/man-REM

These cost/benefit ratios are all small relative to the $1000/man-REM averted guideline which is often used as a reasonable criteria for cost/benefit effectiveness. This would imply that all these modifications are cost-effective from a risk-averted viewpoint.

Table 48

Value/Impact Results

Modification A Replace CO_2 with Halon in CV/T

Risk = 821.3 - 285.6 = 535.7 man-REM/yr

Cost = \$50K to \$100K

$\frac{\text{Value}}{\text{Impact}}$ = \$93.3/man-REM/yr to \$186.7/man-REM/yr

Modification B Re-route one train of affected system

Risk = 821.3 - 58.1 = 763.2 man-REM/yr

Cost = \$5-\$50K

$\frac{\text{Value}}{\text{Impact}}$ = \$6.5/man-REM/yr to \$65/man-REM/yr

Modification C Replace Relays w/Non-chattering circuits

Risk = 10.8 - 0.0 = 10.8 man-REM/yr

Cost \$10K x 5 systems = \$50K

$\frac{\text{Value}}{\text{Impact}} = \frac{\$50K}{10.8}$ = \$4629.6/man-REM/yr

7.0 SUMMARY AND CONCLUSIONS

A number of general insights into the potential problems associated with inadvertent actuations of fire suppression systems have been obtained. The review of the LER data base substantiated the observation that such events tend to occur with a relatively high frequency of 0.12 per reactor year, and thus can be expected at some time in the life of any particular plant. In 78% of the events inadvertant actuation of water systems was involved, while CO_2 and Halon actuations each accounted for 11% of the events. It was found that inadvertant actuations resulted in damage to other nearby plant equipment in 60% of the events. For those inadvertant actuation events involving damage to other components, 84% were due to water systems, with the remainder due to CO_2 systems. No event in which Halon damaged other equipment was found, although in principle, this is possible. In particular, cables were found to be vulnerable primarily to water, while damage to cables due to CO_2 was found in only one event.

Ten different root causes of inadvertent FSS actuations were identified, due to either random events, fire events, seismic events, or fires external to the plant boundary. The accident sequences which could result from these 10 root causes of inadvertent FSS actuations were found to be either general transients (with the PCS initially available) or transients associated with seismically-induced loss of offsite power. For the PWR examined, some of these transients led to loss of coolant inventory inside containment through reactor coolant pump seal LOCAs or stuck-open PORVs.

The impact of these 10 root causes of inadvertant FSS actuation was evaluated for a prototypical PWR plant. The vital area analysis performed for the plant showed that there were a relatively large number of fire zones (both as singles and in conjunction with random failure events), for which inadvertent FSS actuation could lead to core damage. This observation is significant in a generic sense, for it would lead one to believe that a similarly large number of critical areas would be found at any plant. The same observation applies both to seismically-induced FSS actuations as well as fire and random failure-induced actuations.

The scoping quantification showed that certain inadvertent actuation scenarios could result in incremental increases in core damage frequency in the range of 10^{-5} to 10^{-4} per year based on the the parameter values used in this study. This was shown to correspond to incremental increases in offsite dose of 58 to 821 man-REM/year. A simple cost/benefit calculation showed that the fixes proposed to reduce (or prevent) such inadvertant actuations would be cost-effective from a risk-averted viewpoint.

Based on the assumptions made in this scoping study relative to the effects of FSS agents on equipment, the core damage frequencies were found to be relatively high. Unfortunately, little or no data exists on the effects of the FSS agents on different types of cables or active electro-mechanical equipment, so it is not currently possible to further refine these assumptions. While the assumption that the effects of Halon on equipment are similar to those of CO_2 is not consistent with the limited data reviewed in the LER data base, from a generic viewpoint such an assumption must be made until actual data show otherwise.

In the same vein, little or no data exist on the probability of breach of fire barriers in the presence of smoke or steam, yet the spread of smoke is potentially an important cause of inadvertant FSS actuation. Clearly, additional effort to develop such data is warranted if further (more refined) studies are to be made.

One additional generic insight obtained has to do with diesel generator rooms which use either CO_2 or Halon for fire suppression. In order to maintain the required concentration of suppressant in the room, it is necessary to seal off the room given FSS actuation. It is generally thought that this can result in overheating of the diesels themselves. If there is a fire in the room, the philosophy is that it is more important to suppress the fire than to worry about the potential vulnerability of the emergency diesel generator overheating due to loss of room cooling. However, when there is an inadvertent actuation, the diesel is needlessly incapacitated. If an inadvertant actuation were to occur in several diesel rooms simultaneously, a potentially significant common-cause failure of the diesels could occur.

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APPENDIX A

SUMMARY CHECKLISTS FOR INADVERTENT
FIRE SUPPRESSION SYSTEM ACTUATIONS
IDENTIFIED IN LER REVIEW COVERING
APRIL 1, 1980 THROUGH JUNE 3,1988

A

Inadvertent Actuation of Fire Suppression System Checklist

Plant: HATCH 1 Type: BWR
Date of incident: 11-92

1. % power/mode? Refueling

2. Initiator? Drop in air pressure in detection system

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Air Pilot Detection System

6. Affected area(s) of plant? ?

7. Affected plant system(s)? ?

8. Affected equipment? ?

9. Failure mode? ?

10. Result in a plant transient? ?

11. Result of a plant transient? ?

12. Result of a fire elsewhere? No

The loss of an air compressor caused a drop in pressure in the air pilot detection system. This drop actuated an unspecified deluge valve.

Inadvertent Actuation of Fire Suppression System Checklist

Plant: OYSTER CREEK Type: BWR
Date of incident: 9-30-80

1. % power/mode? 99%

2. Initiator? Personnel error

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Water spray

5. Component(s) of fire suppression system which failed/initiated actuation?

6. Affected area(s) of plant?

7. Affected plant system(s)? Core Spray System

8. Affected equipment? Booster Pumps

9. Failure mode? Wetting of Pump Motor Wiring

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Maintenance personnel not following proper procedures inadvertently activated fire protection system over core spray booster pumps, wetting booster pump wiring. Details on how system was activated not specified.

#5

Inadvertent Actuation of Fire Suppression System Checklist

Plant: OYSTER CREEK Type: BWR
Date of incident: 6-12-85

1. % power/mode? 100%
2. Initiator? Steam from Scram Discharge Volume
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ?
6. Affected area(s) of plant? Reactor Building 51' Elevation
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? None
10. Result in a plant transient? No
11. Result of a plant transient? Yes
12. Result of a fire elsewhere? No

During an automatic reactor scram, one of two scram discharge volumes did not isolate. Escaping steam from the unisolated scram discharge volume actuated the deluge system at the reactor building 51' elevation. Subsequently, a cleanup system isolation valve failed to open on command because its breaker had tripped. (It is not clear whether the deluge caused the breaker trip.) Manual procedures were used to complete the reactor shutdown.

* 8

Inadvertent Actuation of Fire Suppression System Checklist

Plant: DRESDEN 2 Type: BWR
Date of incident: 12-23-81

1. % power/mode? 100%
2. Initiator? High humidity/dust in HPCI room.
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Ionization detector
6. Affected area(s) of plant? HPCI room.
7. Affected plant system(s)? HPCI system
8. Affected equipment? " "
9. Failure mode? Water in HPCI oil sample
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During normal operation, high concentration of humidity and dust particles in HPCI room sets off ionization detector, actuating fire deluge system. Water was found in an HPCI oil sample, so the High Pressure Coolant Injection system was declared inoperable. (Coincidentally, the auto-depressurization system was found to be inoperable because of a broken wire.)

#9

Inadvertent Actuation of Fire Suppression System Checklist

Plant: DRESDEN 2 Type: BWR
Date of incident: 4-9-87

1. % power/mode? 0 %

2. Initiator? Contractor Personnel error

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Halon

5. Component(s) of fire suppression system which failed/initiated actuation? ?

6. Affected area(s) of plant? Auxiliary Electric Equipment Room

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Contractor personnel inadvertently actuated Halon fire suppression system in auxiliary electrical equipment room. No plant equipment was damaged, although the Halon system was temporarily inoperable.

#10

Inadvertent Actuation of Fire Suppression System Checklist

Plant: GINNA Type: PWR
Date of incident: 11-14-81

1. % power/mode? ? (Fire Study says 100%)
2. Initiator? Personnel error
3. How many fire suppression systems actuated? Several
4. Suppression system(s) involved? Water spray (Deluge implied)
5. Component(s) of fire suppression system which failed/initiated actuation? Control circuits to solenoid valves
6. Affected area(s) of plant? Several (unspecified)
7. Affected plant system(s)? Reactor Protection System, Control Rod Drive System
8. Affected equipment? RPS Motor Generator Set, CRD Switchgear Cabinet
9. Failure mode? Trip of RPS Motor Generator, Water shorted CRD circuits
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During a test on Satellite Station A, workers inadvertently activate the control circuits to the waterspray solenoid valve actuators, actuating the sprinkler systems in several plant areas. Some water entered the control rod drive switchgear cabinet, causing two control rods to be misaligned to the fully withdrawn position. The water also tripped one Reactor Protection System motor generator set. Operators manually tripped the reactor.

#11

Inadvertent Actuation of Fire Suppression System Checklist

Plant: DRESDEN 3 Type: BWR
Date of incident: 11-30-81

1. % power/mode? Startup
2. Initiator? High Heat and Humidity
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Ionization detector in HPCI room.
6. Affected area(s) of plant? HPCI Room
7. Affected plant system(s)? High Pressure Coolant Injection System
8. Affected equipment? Unspecified HPCI equipment
9. Failure mode? Water damage to HPCI
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During unit startup, high steam concentration and high temperature in HPCI room activated an ionization-type fire detector. The detector then actuated the HPCI room deluge. The deluge damaged unspecified HPCI equipment in the room because of poor shielding and sealing from the water spray. The High Pressure Coolant Injection system was isolated and the unit was shutdown.

#12

Inadvertent Actuation of Fire Suppression System Checklist

Plant: PALISADES Type: PWR
Date of incident: 5-22-87

1. % power/mode? 40%
2. Initiator? Steam rupture caused by personnel error.
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water sprinklers
5. Component(s) of fire suppression system which failed/initiated actuation? ? (Heat detector?)
6. Affected area(s) of plant? Area near Feedwater Pump
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? None
10. Result in a plant transient? Steam rupture caused reactor trip(?)
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Maintenance personnel errantly close Main Feedwater Pump Turbine Driver Exhaust Valve, causing Turbine Driver's Overpressure Protection Disc to rupture. The escaping high temperature steam actuates local fire protection sprinklers. Operators then initiate plant scram. Apparently, no equipment damaged by sprinklers.

#13

Inadvertent Actuation of Fire Suppression System Checklist

Plant: PALISADES Type: PWR

Date of incident: 7-14-87

1. % power/mode? 91%
2. Initiator? Errant Maintenance Procedure
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ?
6. Affected area(s) of plant? Transformer area
7. Affected plant system(s)? Electric Power system
8. Affected equipment? 1-1, 1-2, 1-3 Startup Transformers
9. Failure mode? Water and wind combine to ground 1-2 transformer. Protective relays then trip breakers for all 3 startup transformers
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Deluge system for startup transformers was inadvertently actuated during maintenance. Water then grounds the 1-2 startup transformer. This ground actuates relays which then trip the breakers for the 1-1, 1-2, and 1-3 startup transformers, thereby causing a loss of off-site power. The reactor was then manually tripped.

#14

Inadvertent Actuation of Fire Suppression System Checklist

Plant: BROWNS FERRY 1 Type: BWR
Date of incident: 5-3-86

1. % power/mode? 0%

2. Initiator? Not specified

3. How many fire suppression systems actuated? Not specified

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Not specified

6. Affected area(s) of plant? Drywell area

7. Affected plant system(s)? Instrumentation, Engineered Safety Features

8. Affected equipment? Drywell pressure sensors; Diesel Generators, Emergency Cooling Pumps, Core Spray Valves

9. Failure mode? Water shorted switch contacts, sensors then activated ESF.

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

On 5-3-86, an electrical short in the high drywell pressure sensors caused a false high pressure signal to be generated. The cause of the short was moisture in the sensors from an unspecified spurious fire spray actuation eight days earlier. The false high pressure signal actuated several engineered safety features including all 8 diesel generators, 2 emergency equipment cooling water pumps, and the core spray injection valve opening. Since the reactor was shutdown, the impact was not serious, but 30,000 gallons of contaminated water did spill into the lower part of the reactor building.

#15

Inadvertent Actuation of Fire Suppression System Checklist

Plant: ROBINSON 2 Type: PWR
Date of incident: 9-11-85

1. % power/mode? ?
2. Initiator? Overheating of Main Transformer C
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ? (Heat detector ?)
6. Affected area(s) of plant? Main Transformer Area
7. Affected plant system(s)? Electric Power
8. Affected equipment? Main Transformer "C" control cabinet
9. Failure mode? Water spraying into open electrical cabinet.
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Heavy rains and defective power supply plug caused a breaker trip that resulted in loss of power to the cooling fans on Main Transformer C. While the Main Transformer C control cabinet was open for troubleshooting, the main transformer deluge system actuated. Deluge water entering the cabinet generated false signals which caused a turbine and reactor trip. The transformer temperature was over 100 C when the deluge actuated.

#17

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SALEM 1 Type: PWR
Date of incident: 11-9-82

1. % power/mode? Refueling

2. Initiator? Spurious -- unknown

3. How many fire suppression systems actuated? "Several" deluge system

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? No apparent cause.

6. Affected area(s) of plant? Fuel Handling Building, Auxiliary Building, and Control Room

7. Affected plant system(s)? Ventilation Systems

8. Affected equipment? Charcoal filters

9. Failure mode? Wetting of filters

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

For no apparent reason, several deluge systems actuated temporarily. The only damage was the wetting of several charcoal filters in the ventilation system.

#19

Inadvertent Actuation of Fire Suppression System Checklist

Plant: PEACH BOTTOM 2 Type: BWR
Date of incident: 9-17-82

1. % power/mode? ?
2. Initiator? Unknown -- spurious
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Unspecified water system
5. Component(s) of fire suppression system which failed/initiated actuation? Spurious actuation of fire suppression valve
6. Affected area(s) of plant? Recombiner Building
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? None
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Spurious actuation of fire suppression valve in recombiner building. Sprinkler water drained to floor sump and mixed with radioactive water, causing sump to overflow. A small quantity of overflowing water escaped building through storm drain system. No equipment damaged.

#21

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SURRY 2 Type: PWR
Date of incident: 12-9-86

1. % power/mode? 100%

2. Initiator? Escaping Steam/Water

3. How many fire suppression systems actuated? 1 (Initially)

4. Suppression system(s) involved? Sprinklers

5. Component(s) of fire suppression system which failed/initiated actuation? Short circuits in fire protection control panel

6. Affected area(s) of plant? Turbine Building, Control Room, Cable Tray Rooms, Emergency Switchgear Rooms

7. Affected plant system(s)? CO_2 suppression system, Halon suppression system, Radio system

8. Affected equipment? Control Panels for CO_2 and Halon; Radio Repeater

9. Failure mode? Water shorted control circuits; CO_2 Iced up Radio Repeater

10. Result in a plant transient? Yes -- Unit 1 was shutdown next day

11. Result of a plant transient? Yes -- coincident with Reactor trip of Unit 2

12. Result of a fire elsewhere? No

Forty seconds after a reactor trip, a main feedwater elbow ruptured, releasing steam and water into the turbine building. This water shorted out the security card readers for all the plant and entered a fire protection control panel through an open conduit, shorting several circuits and actuating 62 sprinkler heads. The sprinkler water leaked into the control panels for the Cable Tray Rooms CO_2 suppression system and for the Emergency Switchgear Rooms Halon suppression system, shorting control circuits and actuating the CO_2 and Halon discharge systems. The main CO_2 supply tank was emptied, CO_2 and Halon leaked into the control room, and a worker was momentarily trapped between the CO_2, the Halon, and an inoperable security door. CO_2 generated 2' snow in Cable Room.

*22N, 23N

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FT. CALHOUN 1 Type: PWR
Date of incident: 7-6-87

1. % power/mode? 100%

2. Initiator? Inadequate Test Procedure

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Dry Pipe

5. Component(s) of fire suppression system which failed/initiated actuation? Dirt in Check Valves interfacing between dry pipe system and instrument air system

6. Affected area(s) of plant? Auxiliary building

7. Affected plant system(s)? Instrument Air System, Diesel Generator

8. Affected equipment? Diesel Generator Exhaust Damper

9. Failure mode? Water-borne residue caused air flow pilot valve to stick.

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

On 7-6-87 during a test of the diesel generator dry pipe fire protection system, water entered the instrument air system from the FPS. The cause was foreign material preventing closure of the check valves interfacing between the two systems. Subsequently, on 9-23-87, during a generator test dirt and residue from this contamination of the air system caused an air flow pilot valve for the diesel generator #2 exhaust damper to stick. This caused the generator to overheat and automatically shutdown. An extensive blowdown of the instrument air system was performed to remove the water.

#26

Inadvertent Actuation of Fire Suppression System Checklist

Plant: PILGRIM 1 Type: BWR
Date of incident: 2-25-83

1. % power/mode? ?
2. Initiator? Incorrect installation of solenoid valve.
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Solenoid deluge valve installed wrong.
6. Affected area(s) of plant? ?
7. Affected plant system(s)? Standby Gas Treatment System (SGTS
8. Affected equipment? Charcoal Filters in B system
9. Failure mode? Wetting of Charcoal Filters
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Incorrect installation of solenoid valve in deluge system resulted in water leaking into SGTS charcoal filters.

#28

Inadvertent Actuation of Fire Suppression System Checklist

Plant: BROWNS FERRY 3 Type: BWR
Date of incident: 1-14-82

1. % power/mode? ?

2. Initiator? Personnel hung coats on spray valve

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Sprinkler

5. Component(s) of fire suppression system which failed/initiated actuation? Fixed Spray Valve

6. Affected area(s) of plant? Staging area

7. Affected plant system(s)? Smoke detection

8. Affected equipment? Smoke detector

9. Failure mode? Water in smoke detector

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Personnel hung coats on fire spray valve, causing inadvertant actuation of the water spray. The water reached a smoke detector which then falsely annunciated. The false alarm could have masked any real alarms from other smoke detectors.

#29

Inadvertent Actuation of Fire Suppression System Checklist

Plant: COOPER Type: BWR
Date of incident: 4-19-84

1. % power/mode? 70 %
2. Initiator? Water hammer caused by improper startup of fire pump.
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Clappers on deluge valves failed
6. Affected area(s) of plant? ?
7. Affected plant system(s)? Standby Gas Treatment System
8. Affected equipment? Charcoal filters
9. Failure mode? Wetting of Charcoal filters
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Bulldozer sheared off fire hydrant, automatically starting fire pumps. Fire pumps were shut off until the hydrant leak was isolated and then were restarted to repressurize the system. Sudden restarting of the electric fire pump generated a system water hammer. The water hammer opened the worn clappers on the automatic deluge valves by the Standby Gas Treatment System. The deluge wetted the charcoal filters on both filter trains. Since the SGTS was inoperable, the reactor was placed in cold shutdown.

30

Inadvertent Actuation of Fire Suppression System Checklist

Plant: CRYSTAL RIVER 3 Type: PWR
Date of incident: 4-1-80

1. % power/mode? 0 %

2. Initiator? Personnel Error

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? ?

6. Affected area(s) of plant? ?

7. Affected plant system(s)? Auxiliary Building Ventilation System

8. Affected equipment? Exhaust Filter (AHFL-2A)

9. Failure mode? Wetting of Filters

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

While attempting to reset a fire service panel alarm, personnel inadvertently actuated the fire deluge system. The deluge wetted one train of the auxiliary building ventilation exhaust filters, requiring replacement.

#36

Inadvertent Actuation of Fire Suppression System Checklist

Plant: RANCHO SECO Type: PWR
Date of incident: 6-25-87

1. % power/mode? 0% (start-up)

2. Initiator? Test of CO_2 system

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Carbon Dioxide

5. Component(s) of fire suppression system which failed/initiated actuation? ?

6. Affected area(s) of plant? Nuclear Service Electrical building

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Following a test of the carbon dioxide discharge system in the Nuclear Service Electrical building, several uncontrolled carbon dioxide discharges occurred. The cause of the uncontrolled discharges is not specified. The area was temporarily abandoned, but no equipment was damaged.

#37

Inadvertent Actuation of Fire Suppression System Checklist

Plant: COOK 1 Type: PWR
Date of incident: 1-18-83

1. % power/mode? "Normal ops" (100%?)

2. Initiator? Spurious -- unknown

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Carbon Dioxide

5. Component(s) of fire suppression system which failed/initiated actuation? ?

6. Affected area(s) of plant? Unit 1 auxiliary cable vault

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

The carbon dioxide system spuriously discharged in the unit 1 auxiliary cable vault. To stop the discharge, isolation of the CO_2 tank from the entire system was required until the local isolation valve was located. No reason for the spurious actuation is given.

#39

Inadvertent Actuation of Fire Suppression System Checklist

Plant: COOK 1 Type: PWR
Date of incident: 12-19-85

1. % power/mode? 90%

2. Initiator? Personnel Error during CO_2 system Test

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? CO_2

5. Component(s) of fire suppression system which failed/initiated actuation? ?

6. Affected area(s) of plant? Auxiliary Building

7. Affected plant system(s)? Fire watch required at 573' Level of Auxiliary Building had to be suspended

8. Affected equipment? None

9. Failure mode? None

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

During a test of the plant carbon dioxide fire protection system, the system was accidentally actuated such that carbon dioxide was discharged. No equipment was damaged, but a fire watch required for another reason at the 573' level of the auxiliary building had to be suspended until the air was cleared.

40

Inadvertent Actuation of Fire Suppression System Checklist

Plant: COOK 2 Type: PWR
Date of incident: 11-9-82

1. % power/mode? ?
2. Initiator? Water in Pyralarm detector
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? CO_2
5. Component(s) of fire suppression system which failed/initiated actuation? Pyralarm detector
6. Affected area(s) of plant? Auxiliary Cable Vault
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Water from an unknown source entered a Pyralarm detector and caused a false fire annunciation. Carbon dioxide was then inadvertantly discharged into the auxiliary cable vault. No equipment was damaged, but isolation of the erroneous alarm also isolated other alarms in the zone.

EA1

Inadvertent Actuation of Fire Suppression System Checklist

Plant: COOK 2 Type: PWR
Date of incident: 1-18-83

1. % power/mode? "Normal ops"

2. Initiator? Water in Pyralarm detector

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? CO_2

5. Component(s) of fire suppression system which failed/initiated actuation? Pyralarm detector

6. Affected area(s) of plant? Auxiliary Cable Vault

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Same as #40.
Also maybe related to #37.
The water source--unspecified--was redirected to a drain.

#43

Inadvertent Actuation of Fire Suppression System Checklist

Plant: COOK 2 Type: PWR
Date of incident: 9-8-85

1. % power/mode? 0%

2. Initiator? Leaky valves

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Sprinkler system

5. Component(s) of fire suppression system which failed/initiated actuation? Leaking sprinkler heads

6. Affected area(s) of plant? ?

7. Affected plant system(s)? 3 Filter Systems

8. Affected equipment? Charcoal adsorbers

9. Failure mode? Wetting of charcoal

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Upon routine inspection, charcoal adsorber banks were found to be wet. The source of the water was leaking sprinkler heads and leaking isolation valves.

(The filters were Unit 1 ACRF, Unit 2 ACRF, and Unit 2 HV-AES-2)

44

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TMI 2 Type: PWR
Date of incident: 6-1-82

1. % power/mode? ?
2. Initiator? Lightning
3. How many fire suppression systems actuated? 2
4. Suppression system(s) involved? Halon, Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Ultraviolet light detector
6. Affected area(s) of plant? Air Intake Tunnel
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? None
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Lightning apparently set off an ultraviolet light fire detector which actuated the Air Intake Tunnel halon system. Actuation of the halon system then activated the air deluge system and tripped the supply and exhaust fans for the auxiliary building and fuel handling building. The deluge activation and fan trips were designed system interlocks. It was 11 days before the halon system was returned to service.

#45

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TMI 2 Type: PWR
Date of incident: 6-29-82

1. % power/mode? ?

2. Initiator? Lightning

3. How many fire suppression systems actuated? 2

4. Suppression system(s) involved? Halon, deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Ultraviolet light detector

6. Affected area(s) of plant? Air Intake Tunnel

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? None

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Same as #44, except halon system out of service for 10 days.

Note: The actuations described in #44, 45, 47, and 48 were all caused by the same ultraviolet light detectors. Furthermore, the bad experience with these detectors caused plant personnel to intentionally disable these detectors on several occasions as reported in #47, 50, and 51.

#46

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TMI 2 Type: PWR
Date of incident: 2-16-83

1. % power/mode? ?
2. Initiator? Failed heat tracing
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Frozen deluge pipes
6. Affected area(s) of plant? Air Intake Tunnel
7. Affected plant system(s)? Halon System
8. Affected equipment? Halon System Heat Detectors
9. Failure mode? Detectors submerged under water
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

On 2-16-83, routine inspection discovered standing water on the floor of the Air Intake Tunnel. The high water level was due to freeze-induced leaks in the deluge system. The deluge froze because of failed heat tracing on the deluge pipes. Also, Two alarms to indicate the high sump level failed to annunciate, allowing 1 or 2 halon system heat detectors to be submerged.

#A7

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TMI 2 Type: PWR
Date of incident: 3-3-83

1. % power/mode? ?

2. Initiator? Unknown

3. How many fire suppression systems actuated? 2

4. Suppression system(s) involved? Halon, Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Unknown

6. Affected area(s) of plant? Air Intake Tunnel

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? None

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Similar to #44, #45, although reason for actuation could not be determined. Halon system unavailable for 8 days.

#48

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TMI 2 Type: PWR
Date of incident: 5-6-83

1. % power/mode? ?

2. Initiator? Welding activity

3. How many fire suppression systems actuated? 2

4. Suppression system(s) involved? Halon, deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Ultraviolet light detector

6. Affected area(s) of plant? Air Intake Tunnel

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? None

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Welding activity near the Air Intake Tunnel actuates an ultraviolet light fire detector. The detector initiates halon system discharge which then triggers the deluge system and trips the supply and exhaust fans for the auxiliary building and fuel handling building ventilation systems. The halon system was out of service for 14 days after this event. This event is similar to #44, 45, and 47.

#52 Ex

Inadvertent Actuation of Fire Suppression System Checklist

Plant: HATCH 1 Type: BWR
Date of incident: 4-7-81

1. % power/mode? ?
2. Initiator? Test procedure
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Deluge valve actuated
6. Affected area(s) of plant? Cooling tower "C"
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During a fire pump test, the test valve was opened to measure pump flow. Subsequently, a diesel fire pump overcrank alarm was received and the pump was turned off. Since the test valve was still open, the fire system depressurized, causing the actuation of the cooling tower "C" deluge valve. Soon after, the pump was restarted and the deluge valve was reset.

#53

Inadvertent Actuation of Fire Suppression System Checklist

Plant: HATCH 1 Type: BWR
Date of incident: 5-15-85

1. % power/mode? 100%
2. Initiator? Personnel error
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ~~Ins~~trument Water Valve
6. Affected area(s) of plant? Control Room
7. Affected plant system(s)? HPCI, Low-Low Set Safety Relief Valve, Reactor Pressurization Sys., Control Room HVAC
8. Affected equipment? Analog Transmitter Trip System Panel, HVAC Charcoal Filters
9. Failure mode? Water shorted circuits in ATTS Panel, wetted charcoal filters
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Personnel dragged an overhead crane hook on an instrument water supply vent valve, damaging the valve. The loss of pressure in the pipe actuated the deluge for the control room HVAC "A" filter train. The water soaked the "A" charcoal filters and then backed up in the ventilation ducts because of plugged drains to drip out of a control room vent onto an Analog Transmitter Trip System panel. The water entered the panel to cause the "A" Low-low Set Safety Relief Valve to fail open, to cause the HPCI trip solenoid to temporarily energize, and to cause the failure of an ATTS power supply. Since the LLS SRV was failed open, the reactor was manually scrammed.

#54

Inadvertent Actuation of Fire Suppression System Checklist

Plant: HATCH 1 Type: BWR
Date of incident: 6-27-85

1. % power/mode? 64 %
2. Initiator? Personnel error
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Closing of deluge valve diaphragm chamber water supply valve
6. Affected area(s) of plant? ?
7. Affected plant system(s)? "A" and "B" 4160 Volt Busses
8. Affected equipment? Startup Transformer "1C", Reactor Recirculation Pumps
9. Failure mode? Water caused phase-to-ground fault trip on transformer
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Worker closes the wrong valve (deluge valve diaphragm chamber water supply valve), inadvertently actuating the deluge over the "1C" Startup transformer. The water causes a phase-to-ground fault which trips the transformer. The trip results in a loss of power to the plant "A" and "B" 4160 Volt busses. Consequently, the "A" and "B" reactor recirculation pumps lose power and the plant is scrammed.

#55

Inadvertent Actuation of Fire Suppression System Checklist

Plant: HATCH 1 Type: BWR
Date of incident: 3-11-86

1. % power/mode? 0 % - Refueling
2. Initiator? Failure in deluge valve seat
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Leaking deluge valve
6. Affected area(s) of plant?
7. Affected plant system(s)? Standby Gas Treatment System
8. Affected equipment? 1A Charcoal Adsorbers
9. Failure mode? Wetting of charcoal
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

A leaking fire protection system deluge valve wet the charcoal adsorbers in the 1A Standby Gas Treatment System. The leaky valve was replaced on 11-24-85, but the wet charcoal was not noticed until 3-11-86.

*56
N

Inadvertent Actuation of Fire Suppression System Checklist

Plant: HATCH 1 Type: BWR
Date of incident: 10-8-87

1. % power/mode? 100%

2. Initiator? - Improper Maintenance

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Leaking Clearance Boundary Valv

6. Affected area(s) of plant? ?

7. Affected plant system(s)? Standby Gas Treatment System

8. Affected equipment? Carbon Filters

9. Failure mode? Wetting of Filters

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Improper maintenance procedure caused a leaking clearance boundary valve to wet the carbon filters in Standby Gas Treatment System "A" Filter train.

#57

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SHOREHAM Type: BWR
Date of incident: 9-8-86

1. % power/mode? 0%
2. Initiator? Improper maintenance procedure
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? CO_2
5. Component(s) of fire suppression system which failed/initiated actuation? CO_2 Master Control Valve; CO_2 Selector Control Valve
6. Affected area(s) of plant? Normal Switchgear Room, Control Building
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Improper maintenance procedure resulted in the loss of power to the carbon dioxide master control valve. The master control valve opened, admitting carbon dioxide to the selector control valve for the normal switchgear room. The selector control valve was open slightly because of two screws wedged into the value seat. This slight opening allowed carbon dioxide to be released into the normal switchgear room. The control building and normal switchgear room were evacuated for 1 hour.

•60 Ex

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SEQUOYAH 1 Type: PWR
Date of incident: 6-29-86

1. % power/mode? 0%
2. Initiator? Moisture shorted relay contacts
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water spray
5. Component(s) of fire suppression system which failed/initiated actuation? Sudden pressure relay failed on transformer
6. Affected area(s) of plant? Transformer area
7. Affected plant system(s)? Electrical Busses
8. Affected equipment? Common Station Service Transformers C and D
9. Failure mode? Busses did not fail, but were shifted.
10. Result in a plant transient? No - 0%
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Moisture shorted the contacts on a microswitch within the sudden pressure relay on common station service transformer (CSST) "D". The short actuated the fire suppression system which sprayed CSST "D" with water. The suppression actuation tripped CSST "C" and "D" off-line. The transient undervoltage experienced as the busses they were carrying shifted to another CSST caused the automatic starting of the diesel generators. The generators were soon stopped and no equipment damage occurred.

#65

Inadvertent Actuation of Fire Suppression System Checklist

Plant: ARNOLD Type: BWR
Date of incident: 3-2-82

1. % power/mode? ?

2. Initiator? Leaky Valve.

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Leaking deluge valve and plugged drain

6. Affected area(s) of plant? ?

7. Affected plant system(s)? Standby Gas Treatment System

8. Affected equipment? Charcoal bed in "A" train

9. Failure mode? Wetting of charcoal

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

During testing, the "A" charcoal bed in the Standby Gas Treatment was found to be wet. The cause was a leaking deluge valve in combination with a plugged deluge drain line.

#66

Inadvertent Actuation of Fire Suppression System Checklist

Plant: ARNOLD Type: BWR
Date of incident: 3-16-83

1. % power/mode? ?
2. Initiator? Leaky valve
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Leaking deluge valve
6. Affected area(s) of plant? ?
7. Affected plant system(s)? Standby Gas Treatment System
8. Affected equipment? Charcoal Bed
9. Failure mode? Wetting of charcoal
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During inspection, the "B" charcoal bed in the Standby Gas Treatment System was found degraded by leaking water from the deluge system. The drain line contributed by directing the water into the charcoal bed.
(Similar to #65)

#68

Inadvertent Actuation of Fire Suppression System Checklist

Plant: ARNOLD Type: BWR
Date of incident: 11-23-84

1. % power/mode? 81%

2. Initiator? Slow leak in pressurized sensing header

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Leaking pressurized sensing header; Clogged pressure regulator

6. Affected area(s) of plant? ?

7. Affected plant system(s)? Non-vital electrical busses

8. Affected equipment? Startup Transformer

9. Failure mode? Water shorted out transformer

10. Result in a plant transient? Yes

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

A slow leak in a pressurized sensing header surrounding the startup transformer coupled with foreign material clogging the pressure regulator leading to the header caused the deluge system over the startup transformer to actuate. The deluge then caused a short in the startup transformer so that the transformer tripped. This trip resulted in the loss of the non-vital electrical busses, a turbine trip, and a reactor scram.

#72

Inadvertent Actuation of Fire Suppression System Checklist

Plant: ARNOLD Type: BWR
Date of incident: 10-15-86

1. % power/mode? 94%
2. Initiator? Incorrect Test Procedure
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Open deluge isolation valve.
6. Affected area(s) of plant? Control Building
7. Affected plant system(s)? Standby Filter Units
8. Affected equipment? Charcoal beds
9. Failure mode? Wetting of charcoal
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

The deluge system for the Standby Filter Units was disconnected from the main deluge system for a test. As part of the test, the deluge isolation valves were commanded open. The test procedure omitted a step to close the isolation valves. Consequently, when the deluge system was reconnected, the SFU's were sprayed with water, disabling both SFU's.

#73

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FITZPATRICK Type: BWR
Date of incident: 5-25-86

1. % power/mode? 100%
2. Initiator? Faulty Test Procedure
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water Spray
5. Component(s) of fire suppression system which failed/initiated actuation? ?
6. Affected area(s) of plant? ?
7. Affected plant system(s)? HPCI, Main Steam Line Drain
8. Affected equipment? Battery Motor Control Center, Valve breakers
9. Failure mode? Water caused trip of breakers that control valves
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During a test of the water spray fire protection system, some of the water drained onto a battery motor control center and into two valve breaker cubicles. The two breakers tripped, rendering the High Pressure Coolant Injection (HPCI) steam supply valve and the main steam line drain outboard isolation valve inoperable. The main steam line drain valve did not present a safety issue, but the HPCI valve caused the HPCI system to be unusable.

#74

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FITZPATRICK Type: BWR
Date of incident: 12-23-86

1. % power/mode? 82%

2. Initiator? Crack in pipe coupling

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Water spray

5. Component(s) of fire suppression system which failed/initiated actuation? Pipe Coupling on Fire Curtain #1 Manifold

6. Affected area(s) of plant? ?

7. Affected plant system(s)? HPCI, PCIS, Monitor on steam drain valve

8. Affected equipment? Battery Motor Control Center 2

9. Failure mode? Water short circuited a resistor on monitor; HPCI + PCIS did not fail

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

A test line coupling on the fire curtain #1 manifold cracked. Water leaking from the crack reached the battery motor control center #2, wetting two rows of breaker cubicles and causing a resistor in the breaker to main steam line drain valve loss of power monitor to fail. The valves controlled by the breakers remained operable until the BMCC was de-energized for repairs. De-energizing the BMCC caused the High Pressure Coolant Injection and the Primary Containment Isolation System to be temporarily inoperable.

#76

Inadvertent Actuation of Fire Suppression System Checklist

Plant: MILLSTONE 2 Type: PWR

Date of incident: 10-9-82

1. % power/mode? ?
2. Initiator? Personnel error (clumsiness)
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Halon
5. Component(s) of fire suppression system which failed/initiated actuation? Fire station box pull handle
6. Affected area(s) of plant? Computer room
7. Affected plant system(s)?
8. Affected equipment? Plant computer
9. Failure mode? Automatic shutdown after halon actuation.
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

A construction worker bumped a fire station box pull handle with some construction material, actuating the computer room halon system. The halon actuation automatically shutdown the plant computer.

#80

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TROJAN Type: PWR
Date of incident: 7-28-81

1. % power/mode? ?

2. Initiator? Welding

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? ?

6. Affected area(s) of plant? ?

7. Affected plant system(s)? Hydrogen Recombiner

8. Affected equipment? B train control power transformer

9. Failure mode? Water short circuited transformer

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

Welding activity acuated the fire deluge system inadvertently. The deluge water short circuited the control power transformer to the hydrogen recombiner B train, resulting in the B train recombiner becoming inoperable.

#87

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FARLEY 1 Type: PWR
Date of incident: 6-10-81

1. % power/mode? ?
2. Initiator? Improper maintenance (Personnel error)
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Pressurization of deluge sensing lines.
6. Affected area(s) of plant? Cooling Tower 2B
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Improper maintenance results in a loss of air pressure in the cooling tower 2B deluge system sensing lines. As a result, the deluge system actuated. The only impact was to temporarily lower the water level in the deluge tanks below the requirement.

#18

Inadvertent Actuation of Fire Suppression System Checklist

Plant: TROJAN Type: PWR
Date of incident: 3-9-85

1. % power/mode? 100%
2. Initiator? Broken feedwater pipe
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ?
6. Affected area(s) of plant? Turbine building
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? None
10. Result in a plant transient? No
11. Result of a plant transient? Yes
12. Result of a fire elsewhere? No

The pressure surge from a turbine trip ruptured an eroded section of the heater drain discharge piping. The escaping 350 F steam-water mixture actuated the fire deluge system in the turbine building. The steam damaged secondary plant equipment in the area and injured one person. The cause of the reactor trip was a turbine trip initiated because of a spurious main turbine bearing high vibration indication.

#93

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FARLEY 1 Type: PWR
Date of incident: 7-21-81

1. % power/mode? ?
2. Initiator? Personnel error during test
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Test regulator in air pressure system
6. Affected area(s) of plant? Cooling tower 2B
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Improper performance of a deluge system test procedure resulted in an air pressurization system test regulator allowing the deluge system air pressure to decrease. The decreased air pressure allowed the cooling tower 2B deluge system to actuate. The only impact was a temporary drop in the deluge system water supply. (Similar to #82)

#84

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FARLEY 1 Type: PWR
Date of incident: 10-28-81

1. % power/mode? ?

2. Initiator? Undetermined--spurious

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Undetermined

6. Affected area(s) of plant? Cooling tower 1A

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

The cooling tower 1A deluge system spuriously actuated. No conclusive reason for the actuation could be determined. The only impact was a temporary drop in the deluge system water supply. (Similar to #82 and 83)

#85

Inadvertent Actuation of Fire Suppression System Checklist

Plant: FARLEY 1 Type: PWR

Date of incident: 3-10-82

1. % power/mode? ?
2. Initiator? Personnel error during maintenance
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Regulator in deluge air pressurization system
6. Affected area(s) of plant? Cooling tower 1A
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Improper maintenance allowed the pressure to drop in the deluge air pressurization system. This drop actuated the cooling tower 1A deluge. The only impact was a temporary lowering of the water lever in the deluge supply tanks. (Similar to #82, 83, 84)

#96

Inadvertent Actuation of Fire Suppression System Checklist

Plant: LIMERICK 1 Type: BWR
Date of incident: 4-10-85

1. % power/mode? 3%
2. Initiator? Pressure spike in switching from Fan A to Fan B
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Halon
5. Component(s) of fire suppression system which failed/initiated actuation? Heat Detector
6. Affected area(s) of plant? Auxiliary Equipment Room, Main Control Room
7. Affected plant system(s)? Ventilation
8. Affected equipment? —
9. Failure mode? None Halon in Equipment Room forced the isolation of the Main Control Room ventilation
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Maintenance workers unintentionally tripped off the auxiliary equipment room supply fan "A". When the standby supply fan "B" automatically started, it generated a pressure spike which set off an overly sensitive heat detector. The heat detector then actuated the halon discharge into the auxiliary equipment room. This discharge forced the isolation of the main control room ventilation system.

#99

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 2 Type: PWR
Date of incident: 2-14-82

1. % power/mode? 0% (Fuel Loading)
2. Initiator? Personnel error during maintenance
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Deluge isolation valve
6. Affected area(s) of plant? Control Room
7. Affected plant system(s)? Control Room Emergency Air Cleanup System
8. Affected equipment? Charcoal Filters
9. Failure mode? Wetting of charcoal in primary system
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During installation of deluge fire protection system, an operator opens the deluge isolation valve which, since the local deluge valve had already been tripped open, actuated the deluge over the control room emergency air cleanup system charcoal filters. The saturated charcoal filters required replacement.

#79

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 2 Type: PWR
Date of incident: 3-3-82

1. % power/mode? ?
2. Initiator? Personnel error during maintenance
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water spray
5. Component(s) of fire suppression system which failed/initiated actuation? Spray System Block Valve
6. Affected area(s) of plant? Cable riser shaft
7. Affected plant system(s)?
8. Affected equipment? Cable tray fire retardant barrier
9. Failure mode? Water damage to barrier material
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During a maintenance procedure, personnel misunderstood spray system block value status and began maintenance on a manual switch while the block valve was still open. As a result, the cable riser shaft water spray was inadvertently actuated. The water damaged the cable tray fire retardant barrier material.

#90

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 2 Type: PWR
Date of incident: 6-8-82

1. % power/mode? ?

2. Initiator? Unknown - spurious (Personnel error?)

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Deluge manual actuator

6. Affected area(s) of plant? ?

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

For some undetermined reason, manual actuation of a deluge valve occurred, inadvertently activating the deluge system. The affected area is not specified. No equipment was damaged

#91

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 2 Type: PWR
Date of incident: 10-17-93

1. % power/mode? Mode 1

2. Initiator? Unknown - spurious

3. How rany fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Unknown

6. Affected area(s) of plant? Control Building North Cable Riser Are

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

The deluge in the control building north cable riser area spuriously actuated. No cause for the actuation could be determined, and no other equipment was affected.

#92

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 2 Type: PWR
Date of incident: 6-16-84

1. % power/mode? 100%
2. Initiator? Leaking test valve in fire main
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? ? (Fire main)
5. Component(s) of fire suppression system which failed/initiated actuation? Ruptured Fire Main pipe
6. Affected area(s) of plant? Unit 1 4KV Switchgear Room
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During pressure testing of a new section of fire main piping, the hydrostatic test boundary valves leaked, pressurizing the entire fire main above the normal operating pressure. A weakened section of the fire main broke, flooding the Unit 1 4KV switchgear room. No equipment damage, other than the pipe break, is described.

#93

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 3 Type: PWR
Date of incident: 2-24-83

1. % power/mode? Mode 5
2. Initiator? Unknown - spurious
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Water spray
5. Component(s) of fire suppression system which failed/initiated actuation? Unknown (Fire detector?)
6. Affected area(s) of plant? Cable Tunnel section 10
7. Affected plant system(s)? None (May have caused the deluge panel corrosion described in #97.)
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

The deluge spray in cable tunnel section 10 spuriously actuated. The cause is unknown, although construction activity in the area probably was a contributor. It took 10 days to restore the actuating fire detector.

99

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 3 Type: PWR
Date of incident: 2-22-83

1. % power/mode? Mode 5
2. Initiator? Unknown - spurious
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Sprinkler
5. Component(s) of fire suppression system which failed/initiated actuation? Unknown (Fire detector?)
6. Affected area(s) of plant? Diesel Generator area
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

The sprinkler over the diesel generator (#G-0[illegible]) spuriously actuated. No reason for the actuation could be determined. It took 3 days to restore the fire detector.

#95

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 3 Type: PWR
Date of incident: 3-31-83

1. % power/mode? Mode 5
2. Initiator? Unknown—spurious
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Unknown (Fire detector?)
6. Affected area(s) of plant? Control building cable riser 30' elevation
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

The deluge spray in control building cable riser 30' elevation spurious actuated. No reason for the actuation could be found. It was 30 days before the associated fire detectors were restored to service.

* 96

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 3 Type: PWR
Date of incident: 4-4-83

1. % power/mode? Mode 5
2. Initiator? Unknown - spurious
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge spray
5. Component(s) of fire suppression system which failed/initiated actuation? Unknown (Failed detectors?)
6. Affected area(s) of plant? Radwaste building cable gallery
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

The fire spray system that protects the radwaste building cable gallery spuriously actuated. No cause for the actuation could be found. The associated fire detectors were out of service for 12 days.

#98

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SAN ONOFRE 3 Type: PWR
Date of incident: 7-28-83

1. % power/mode? Mode 4

2. Initiator? Maintenance activity

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Manual actuation trip lever

6. Affected area(s) of plant? Zone 68 (?)

7. Affected plant system(s)? None

8. Affected equipment? None

9. Failure mode? N/A

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

During cable tray cleaning, a worker accidentally pulled a deluge manual actuation trip lever. This inadvertently actuated the deluge system in zone 68.

*102

Inadvertent Actuation of Fire Suppression System Checklist

Plant: MCGUIRE 1 **Type:** PWR
Date of incident: 7-6-81

1. **% power/mode?** ?
2. **Initiator?** Personnel error
3. **How many fire suppression systems actuated?** 1
4. **Suppression system(s) involved?** Halon
5. **Component(s) of fire suppression system which failed/initiated actuation?** Pushbutton switch
6. **Affected area(s) of plant?** Turbine driver auxiliary feedwater pump area.
7. **Affected plant system(s)?** None
8. **Affected equipment?** None
9. **Failure mode?** None
10. **Result in a plant transient?** No
11. **Result of a plant transient?** No
12. **Result of a fire elsewhere?** No

During a maintenance activity, personnel miscommunication and a sticking pushbutton switch combined to cause the discharge of the halon system reserve cylinder protecting the turbine driven auxiliary feedwater pump.

#106

Inadvertent Actuation of Fire Suppression System Checklist

Plant: WATERFORD 3 Type: PWR

Date of incident: 10-28-85

1. % power/mode? 100%
2. Initiator? Steam leak
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ?
6. Affected area(s) of plant? Feedwater Pump area
7. Affected plant system(s)? ?
8. Affected equipment? Main Feedwater Pump "B"
9. Failure mode? Water
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

A steam leak from the suction flange of the main feedwater pump "B" actuated the deluge system directly above the pump. The deluge water sprayed on and into the pump control cabinet causing the pump to trip. The pump trip resulted in a rapid increase in pressurizer pressure and consequently a reactor trip.

#107

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SUSQUEHANNA 1 Type: BWR
Date of incident: 10-18-82

1. % power/mode? ?

2. Initiator? Clumsy personnel

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Heat sensing thermo-switch

6. Affected area(s) of plant? ?

7. Affected plant system(s)? ?

8. Affected equipment? CREOASS "Control Room Emerg. Operation Air Safety" (?) Charcoal bed train "A"

9. Failure mode? Wetting of charcoal

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

A construction worker bumped a deluge system heat sensing thermo-switch, actuating the deluge over the CREOASS (?) "A" train charcoal bed. The "A" train was inoperable until the charcoal was replaced.

#109

Inadvertent Actuation of Fire Suppression System Checklist

Plant: SUMMER 1 Type: PWR
Date of incident: 9-25-82

1. % power/mode? Mode 1
2. Initiator? Pressure surge during fire pump test
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Deluge valve opened during pressure surge
6. Affected area(s) of plant?
7. Affected plant system(s)? Auxiliary Building Ventilation Exhaust
8. Affected equipment? Charcoal filter Plenum "B"
9. Failure mode? Wetting of Charcoal
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During a test of the auxiliary building sprinkler system, a pressure surge caused by startup of the electric fire pump tripped open a deluge valve. This actuated the deluge system over the auxiliary building charcoal exhaust filter plenum "B", wetting the charcoal.

#110

Inadvertent Actuation of Fire Suppression System Checklist

Plant: WPPSS 2 Type: BWR
Date of incident: 3-21-84 (also 4-19 and 4-27)

1. % power/mode? 1% (Startup)

2. Initiator? Pressure transients in fire water system.

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Deluge

5. Component(s) of fire suppression system which failed/initiated actuation? Sensitive Deluge Valve

6. Affected area(s) of plant?

7. Affected plant system(s)? Standby Gas Treatment System

8. Affected equipment? Charcoal filters in "B" Train

9. Failure mode? No failure (Charcoal tested to be operable)

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

On three occasions between 3-21-84 and 4-27-84, water was found in the Standby Gas Treatment System "B" train. The water came from the deluge system which was believed to have been actuated by pressure transients in the deluge water system. On each occasion, a charcoal test cannister was analyzed, and the charcoal was found to be still operable.

#111

Inadvertent Actuation of Fire Suppression System Checklist

Plant: WPPSS 2 Type: BWR
Date of incident: 9-1-84

1. % power/mode? 65%
2. Initiator? Steam leak
3. How many fire suppression systems actuated? 3
4. Suppression system(s) involved? 1 Deluge, 2 Dry Pipes
5. Component(s) of fire suppression system which failed/initiated actuation? ? (Probably heat detectors)
6. Affected area(s) of plant? Turbine Generator Building, Diesel Generator building, Water Filtration building
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? None
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

A steam leak in the turbine generator building actuated the deluge system nearby. The leak also tripped the pre-action valves in two diesel generator building dry pipe systems. As a result of the deluge actuation the diesel fire pump was started. Five minutes later, the fire pump trouble alarm annunciated. The deluge and dry pipe systems were secured, but, shortly thereafter, a fire alarm in the water filtration building went off. It turned out that the diesel fire pump coolant valve had been closed so that the pump had been running without coolant. The pump had generated smoke in the water filtration building.

#113

Inadvertent Actuation of Fire Suppression System Checklist

Plant: GRAND GULF 1 Type: BWR
Date of incident: 7-13-82

1. % power/mode? ?

2. Initiator? Faulty relay

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? Carbon Dioxide

5. Component(s) of fire suppression system which failed/initiated actuation? Supervisory Relay

6. Affected area(s) of plant? Auxiliary Building

7. Affected plant system(s)? Aux. Building ventilation

8. Affected equipment? None

9. Failure mode? CO_2 contaminated whole aux. building

10. Result in a plant transient? No

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

A faulty fire suppression system supervisory relay actuated the CO_2 discharge system in the Emergency Core Cooling Syatem Penetration room in the auxiliary building. Since the room did not have proper venting, the CO_2 pressure built up and blew open the locked door. This released CO_2 into the rest of the building, forcing evacuation of the whole auxiliary building.

#116

Inadvertent Actuation of Fire Suppression System Checklist

Plant: MILLSTONE 3 Type: PWR
Date of incident: 7-6-87

1. % power/mode? 100 %
2. Initiator? Incorrect test procedure
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? CO_2
5. Component(s) of fire suppression system which failed/initiated actuation? Fire detection system panel
6. Affected area(s) of plant? East MCC/Rod Control area
7. Affected plant system(s)? None
8. Affected equipment? None
9. Failure mode? N/A
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

During a test of the zone modules in the fire detection system panels, the carbon dioxide system in the east MCC/Rod control area was inadvertently actuated. This actuation was due to the omission from the test procedure of the proper reset steps. The affected area had to be evacuated.

#117 R1

Inadvertent Actuation of Fire Suppression System Checklist

Plant: VOGTLE 1 Type: PWR
Date of incident: 6-3-88

1. % power/mode? 100%
2. Initiator? Smoke from electric duct heater
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? ~~Sprinkler~~ Dry Pipe
5. Component(s) of fire suppression system which failed/initiated actuation? Leaky Preaction valve leak-off lines
6. Affected area(s) of plant? Upper Cable Spreading room, Control room
7. Affected plant system(s)? Reactor Coolant system
8. Affected equipment? Process Panels in control room
9. Failure mode? Water in electrical panels
10. Result in a plant transient? No
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Smoke from an electric duct heater actuated smoke detectors. The sprinkler heads did not actuate, but water ran from the preaction valve leakoff lines into the upper cable spreading room and onto the control room ceiling. Since the control room ceiling was not adequately watertight, water seeped into the control room and entered some process panels. The water in the panels caused the spurious actuation of reactor coolant system equipment. Control room personnel promptly corrected the coolant system configuration.

#119 N

Inadvertent Actuation of Fire Suppression System Checklist

Plant: BRAIDWOOD 1 Type: PWR
Date of incident: 9-23-87

1. % power/mode? 38%
2. Initiator? Maintenance procedures
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Deluge test valve
6. Affected area(s) of plant? Transformer area
7. Affected plant system(s)? Electric Busses
8. Affected equipment? Unit auxiliary transformers
9. Failure mode? Deluge actuation caused eighty-six lockout relay to isolate transformers
10. Result in a plant transient? Yes, reactor trip
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Maintenance personnel were reinstalling the handle on a transformer deluge alarm test valve. Since the deluge system had not been isolated before the maintenance work, when the workers inadvertently turned the valve stem, it actuated the deluge system over a unit auxiliary transformer. The deluge actuation then activated the eighty-six lockout relay, electrically isolating both unit auxiliary transformers. This isolation led to a turbine trip and a reactor trip.

#120

Inadvertent Actuation of Fire Suppression System Checklist

Plant: RIVERBEND 1 Type: BWR
Date of incident: 1-7-86

1. % power/mode? 3% (Startup)

2. Initiator? Construction worker

3. How many fire suppression systems actuated? 1

4. Suppression system(s) involved? "Water Curtain"

5. Component(s) of fire suppression system which failed/initiated actuation? Solenoid activation switch

6. Affected area(s) of plant? ?

7. Affected plant system(s)? Electric Power

8. Affected equipment? 2 Motor Control Centers, Load Center, Transformer

9. Failure mode? Water shorted Load Center

10. Result in a plant transient? Yes

11. Result of a plant transient? No

12. Result of a fire elsewhere? No

A construction worker thought a water curtain solenoid activation switch was a door latch and inadvertently actuated the water curtain. The water ran into two nearby motor control centers, through a floor penetration, and into a load center on the floor below. The water caused a short in the load center, and the short burned up a transformer. The burnt transformer then tripped the breaker feeding that load center and two other load centers. The loss of these three load centers caused a reactor trip.

#121

Inadvertent Actuation of Fire Suppression System Checklist

Plant: RIVERBEND 1 Type: BWR
Date of incident: 5-19-86

1. % power/mode? 73%
2. Initiator? Unspecified?
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? ?
6. Affected area(s) of plant? Main Turbine Building
7. Affected plant system(s)? Main Turbine
8. Affected equipment? Turbine bearing vibration sensor
9. Failure mode? Water in sensor cable connector
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

The deluge system was inadvertently actuated over the main turbine bearings. About 7 hours later, water that had accumulated in the #3 bearing vibration probe cable connector generated a false high vibration signal. This signal caused the closure of the turbine stop values and a reactor scram.

*123

Inadvertent Actuation of Fire Suppression System Checklist

Plant: CALLAWAY 1 Type: PWR
Date of incident: 2-22-85

1. % power/mode? 1%. (Startup)
2. Initiator? Leaky deluge system
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? Deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Leaky Hand Pull Station
6. Affected area(s) of plant? Startup Transformer area
7. Affected plant system(s)? Electric power
8. Affected equipment? Startup transformer, Control Rod Drive
9. Failure mode? Interlock tripped startup transformer
10. Result in a plant transient? Yes
11. Result of a plant transient? No
12. Result of a fire elsewhere? No

Deluge system water leaked into the deluge system hand pull station for the startup transformer. The transformer interlock circuit interpreted this leakage as a deluge actuation and tripped off the startup transformer. Consequently, power was lost to the control rod drive motors and the reactor was manually tripped.

#127

Inadvertent Actuation of Fire Suppression System Checklist

Plant: PALO VERDE 1 Type: PWR
Date of incident: 6-19-86 (actuation on 4-28-86)

1. % power/mode? 100%
2. Initiator? Cleaning activity
3. How many fire suppression systems actuated? 1
4. Suppression system(s) involved? deluge
5. Component(s) of fire suppression system which failed/initiated actuation? Deluge valve
6. Affected area(s) of plant? Train "B" Low Pressure Safety Injection Pump Room
7. Affected plant system(s)? ?
8. Affected equipment? ?
9. Failure mode? ?
10. Result in a plant transient? No
11. Result of a pl nt transient? No
12. Result of a fire elsewhere? No

The train "B" Low Pressure Safety Injection Pump room was being decontaminated on 4-28-86 when the deluge valve began spuriously actuating. As a result, personnel then took the sprinkler system valves out of service and instituted an hourly fire watch. On 6-19-86, the NRC determined that the fire watch was not being conducted properly. Apparently, no other equipment was affected.

APPENDIX B

GENERAL TRANSIENT SEQUENCES

QUANTIFIED FOR THE PROTYPICAL PWR

TABLE 4-A.
SEQUENCE CUTSETS FOR SURRY FSS ROOT CAUSE 1

(AFTER SCREENING OUT CUTSETS THAT DON'T HAVE AT LEAST ONE FIRE ZONE WITH FSS AND SMOKE DETECTORS AND CUTSETS THAT HAVE MORE THAN ONE FIRE ZONE WITHOUT FSS AND SMOKE DETECTORS)

(AFTER SCREENING OUT CUTSETS REQUIRING FSS DAMAGE IN ZONE 31)

(ALSO AFTER SCREENING OUT CUTSETS WITH TWO FIRE ZONES NOT HAVING A DOOR OR CABLE PENETRATION BETWEEN THEM)

SRY-FIRE-SEQ1 =

```
 18   7.7000e-04    FRZ-2 * CPC-CCF-PG-STRAB +
 55   7.0000e-05    FRZ-2 * HPI-CCF-FRCHABCX +
 66   3.0000e-05    FRZ-2 * CPC-CCF-FRSWABX
     -----------
      8.7000E-04  P(fire adjacent to 2)=9.16e-02;
  FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (8.70e-04) * M = 3.19e-09
-----------------
 16   7.7000e-04    FRZ-4 * CPC-CCF-PG-STRAB +
 53   7.0000e-05    FRZ-4 * HPI-CCF-FRCHABCX +
 63   3.0000e-05    FRZ-4 * CPC-CCF-FRSWABX +
     ----------
      8.7000E-04    P(fire adjacent to 4)=4.59e-02;
  FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (8.70e-04) * M = 1.60e-09
-----------------
 12   9.6000e-04    FRZ-4 * CPC-MDP-FRSW10AX * FRZ-45 +          FIRE IN 45
 20   3.8000e-04    FRZ-4 * FRZ-45 * CPC-STR-PGSTREAX +          FIRE IN 45
 30   1.8000e-04    FRZ-4 * FRZ-45 * CPC-STR-PGSTR1AX +          FIRE IN 45
 37   9.0000e-05    FRZ-4 * ACP-BAC-ST4KV1HX * FRZ-45 +          FIRE IN 45
 38   9.0000e-05    FRZ-4 * ACP-BAC-ST1H1X * FRZ-45 +            FIRE IN 45
 43   9.0000e-05    FRZ-4 * ACP-BAC-ST-1H11X * FRZ-45 +          FIRE IN 45
 60   4.0000e-05    FRZ-4 * ACP-TFM-NO1H1X * FRZ-45 +            FIRE IN 45
     -----------
     18.3000E-04   P(fire in 45)=3.71e-03;
  FREQUENCY = (3.71e-03) * (0.1) * (0.1) * (1.83e-03) * M = 2.72e-10
---------------
   2   1.0000e+00    FRZ-31 * FRZ-4 +
              P(fire in 31)=3.21e-02
     FREQUENCY = (3.21e-02) * (0.1) * (0.1) * M = 1.28e-06
```

SRY-FIRE-SEQ2 =

```
  4   1.5000e-04    FRZ-2 * HPI-CCF-FT115CEX +
  9   1.5000e-04    FRZ-2 * HPI-CCF-FT867CDX +
 10   1.5000e-04    FRZ-2 * HPI-CCF-FT115BDX +
 13   1.0000e-04    FRZ-2 * HPI-CKV-FTCV410X +
 14   1.0000e-04    FRZ-2 * HPI-CKV-FTCV225X +
 21   1.0000e-04    FRZ-2 * HPI-CKV-FTCV25X +
 27   4.0000e-05    FRZ-2 * HPI-XVM-PGXV24X +
     ----------
      7.9000E-04    P(fire adjacent to 2)=9.16e-02;
  FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (7.90e-04) * M = 2.90e-09
--------------------
  2   1.5000e-04    FRZ-4 * HPI-CCF-FT867CDX +
```

```
       3   1.5000e-04    FRZ-4 * HPI-CCF-FT115BDX +
       8   1.5000e-04    FRZ-4 * HPI-CCF-FT115CEX +
      16   1.0000e-04    FRZ-4 * HPI-CKV-FTCV25X +
      19   1.0000e-04    FRZ-4 * HPI-CKV-FTCV410X +
      23   1.0000e-04    FRZ-4 * HPI-CKV-FTCV225X +
      26   4.0000e-05    FRZ-4 * HPI-XVM-PGXV24X +
           ----------
           7.9000E-04    P(fire adjacent to 4)=4.59e-02;
    FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (7.9e-04) * M = 1.45e-09


                      SRY-FIRE-SEQ3 =

       7   1.2000e-02    FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
      11   1.2000e-02    FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
      16   1.0000e-03    FRZ-2 * PPS-SOV-FT1455CX +
      20   1.0000e-03    FRZ-2 * PPS-SOV-FT1456X +
      23   6.0000e-04    FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
      27   6.0000e-04    FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
      30   9.0000e-05    FRZ-2 * DCP-BDC-STBUS1BX +
      36   9.0000e-05    FRZ-2 * DCP-BDC-STBUS1AX +
      42   7.0000e-05    FRZ-2 * PPS-CCF-FTPORVX +
      54   2.7000e-05    FRZ-2 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
      55   2.7000e-05    FRZ-2 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
      56   2.7000e-05    FRZ-2 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
      57   2.7000e-05    FRZ-2 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
      69   2.7000e-05    FRZ-2 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
      74   2.7000e-05    FRZ-2 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
      85   1.2000e-05    FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +
      92   1.2000e-05    FRZ-2 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
      94   1.2000e-05    FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +
      95   1.2000e-05    FRZ-2 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +
           ----------
           2.7660E-02    P(fire adjacent to 2)=9.16e-02;
    FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (2.766e-02) * M = 1.01e-07
 ---------------
       6   1.2000e-02    FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
      10   1.2000e-02    FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
      15   1.0000e-03    FRZ-4 * PPS-SOV-FT1456X +
      19   1.0000e-03    FRZ-4 * PPS-SOV-FT1455CX +
      22   6.0000e-04    FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
      26   6.0000e-04    FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
      32   9.0000e-05    FRZ-4 * DCP-BDC-STBUS1AX +
      35   9.0000e-05    FRZ-4 * DCP-BDC-STBUS1BX +
      40   7.0000e-05    FRZ-4 * PPS-CCF-FTPORVX +
      52   2.7000e-05    FRZ-4 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
      53   2.7000e-05    FRZ-4 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
      65   2.7000e-05    FRZ-4 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
      66   2.7000e-05    FRZ-4 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
      68   2.7000e-05    FRZ-4 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
      73   2.7000e-05    FRZ-4 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
      87   1.2000e-05    FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +
      89   1.2000e-05    FRZ-4 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
      96   1.2000e-05    FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +
      98   1.2000e-05    FRZ-4 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +
           ----------
           2.7660E-02    P(fire adjacent to 4)=4.59e-02;
    FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (2.766e-02) * M = 5.08e-08


                      SRY-FIRE-SEQ4 =
```

Root Cause 1
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```
     1   1.0000e+00      FRZ-1 +
                        P(fire in 5 or 17)= 6.83e-02;
                        P(fire next to 1 but not in 5 or 17)=2.33e-02;
         FREQUENCY = [(6.83e-02) * (0.1) * (0.1) * (0.26)] +
                     [(2.33e-02) * (0.1) * (0.1) * (4.4e-02)] = 1.88e-04
---------------------
     2   1.0000e+00      FRZ-3 +
                        P(fire in 5)= 4.40e-03;
                        P(fire next to 3 but not in 5)=3.78e-02;
         FREQUENCY = [(4.4e-03) * (0.1) * (0.1) * (0.26)] +
                     [(3.78e-02) * (0.1) * (0.1) * (4.4e-02)] = 2.81e-05
---------------------
     4   1.0000e+00      FRZ-17 +
                        P(fire next to 17)=3.75e-02;
            FREQUENCY = (3.75e-02) * (0.1) * (0.001) * (4.4e-02) = 1.65e-07


                         SRY-FIRE-SEQ6 =

     4   1.0000e+00      FRZ-17 +
                        P(fire next to 17)=3.75e-02;
          FREQUENCY = (3.75e-02) * (0.1) * (0.001) * Q = 1.88e-10
---------------------
     5   1.0000e+00      FRZ-1 +
                        P(fire next to 1)=9.16e-02;
            FREQUENCY = (9.16e-02) * (0.1) * (0.1) * Q = 4.58e-08
---------------------
     6   1.0000e+00      FRZ-3 +
                        P(fire next to 3)=4.21e-02;
           FREQUENCY = (4.21e-02) * (0.1) * (0.1) * Q = 2.11e-08


                         SRY-FIRE-SEQ7 =

     8   1.8000e-04      FRZ-2 * 3 RANDOM EVENTS +
    12   1.4400e-04      FRZ-2 * 4 RANDOM EVENTS +
    18   7.0000e-05      FRZ-2 * PPS-CCF-FTPORVX +
    24   1.2000e-05      FRZ-2 * 3 RANDOM EVENTS +
    27   1.2000e-05      FRZ-2 * 3 RANDOM EVENTS +
         -----------
         4.1800E-04      P(fire adjacent to 2)=9.16e-02;
   FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (4.18e-04) * Q = 1.91e-11
------------------
     5   1.8000e-04      FRZ-4 * 3 RANDOM EVENTS +
     9   1.4400e-04      FRZ-4 * 4 RANDOM EVENTS +
    15   7.0000e-05      FRZ-4 * PPS-CCF-FTPORVX +
    20   1.2000e-05      FRZ-4 * 3 RANDOM EVENTS +
    23   1.2000e-05      FRZ-4 * 3 RANDOM EVENTS +
         -----------
         4.1800E-04      P(fire adjacent to 4)=4.59e-02;
   FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (4.18e-04) * Q = 9.59e-12


                         SRY-FIRE-SEQ2-B =

     8   1.2000e-02      FRZ-2 * 3 RANDOM EVENTS +
    12   1.2000e-02      FRZ-2 * 3 RANDOM EVENTS +
    15   1.0000e-03      FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
    19   1.0000e-03      FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
    27   6.0000e-04      FRZ-2 * 3 RANDOM EVENTS +
```

```
 31   6.0000e-04    FRZ-2 * 3 RANDOM EVENTS +
 49   9.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
 53   9.0000e-05    DCP-BDC-STBUS1BX * FRZ-2 * LPR-XHE-FOHOTLGX +
 57   7.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
 78   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 79   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 80   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 81   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 89   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 91   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
105   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
109   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
110   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
112   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
      -----------
      2.7660e-02    P(fire adjacent to 2)=9.16e-02;
   FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (2.766e-02) * M = 1.01e-07
-------------------
  7   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
 11   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
 14   1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
 18   1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
 26   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
 30   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
 50   9.0000e-05    DCP-BDC-STBUS1BX * FRZ-4 * LPR-XHE-FOHOTLGX +
 52   9.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
 54   7.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
 73   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 74   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 76   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 77   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 88   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 90   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
106   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
114   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
115   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
116   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
      -----------
      2.7660e-02    P(fire adjacent to 4)=4.59e-02;
   FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (2.766e-02) * M = 5.08e-08


                    SRY-FIRE-SEQ3-B =

                    SRY-FIRE-SEQ4-B =

  4   1.0000e+00    FRZ-2 * LPR-XHE-FOHOTLGX +
                    P(fire adjacent to 2)=9.16e-02;
   FREQUENCY = (9.16e-02) * (0.1) * (0.1) * Q = 4.58e-08
-------------------
  7   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +
 10   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +
 13   1.5000e-04    FRZ-2 * LPR-CCF-FT890ADX +
 14   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +
 18   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +
 23   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +
      -----------
      14.3000e-04   P(fire adjacent to 2)=9.16e-02;
   FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (1.43e-03) * Q = 6.55e-11
-------------------
  1   1.0000e+00    FRZ-4 * LPR-XHE-FOHOTLGX +
```

P(fire adjacent to 4)=4.59e-02;
FREQUENCY = (4.59e-02) * (0.1) * (0.1) * Q = 2.30e-08

```
 5   6.3000e-04   FRZ-4 * LPI-CCF-FSSI1ABX +
 8   3.0000e-04   FRZ-4 * RMT-CCF-FAMSCALX +
11   1.5000e-04   FRZ-4 * LPR-CCF-FT862ABX +
17   1.5000e-04   FRZ-4 * LPR-CCF-FT890ABX +
19   1.5000e-04   FRZ-4 * LPR-CCF-FT860ABX +
24   5.0000e-05   LPR-CCF-PGSUMPX * FRZ-4 +
     -----------
     14.3000e-04   P(fire adjacent to 4)=4.59e-02;
```

FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (1.43e-03) * Q = 3.28e-11

SRY-FIRE-SEQ5-B =

```
 4   6.3000e-04   FRZ-2 * LPI-CCF-FSSI1ABX +
 7   3.0000e-04   FRZ-2 * RMT-CCF-FAMSCALX +
10   1.5000e-04   FRZ-2 * LPR-CCF-FT862ABX +
13   1.5000e-04   FRZ-2 * LPR-CCF-FT863ABX +
15   1.5000e-04   FRZ-2 * LPR-CCF-FT860ABX +
16   5.0000e-05   LPR-CCF-PGSUMPX * FRZ-2 +
     -----------
     14.3000e-04   P(fire adjacent to 2)=9.16e-02;
```

FREQUENCY = (9.16e-02) * (0.1) * (0.1) * (1.43e-03) * Q = 6.55e-11

```
 3   6.3000e-04   FRZ-4 * LPI-CCF-FSSI1ABX +
 6   3.0000e-04   FRZ-4 * RMT-CCF-FAMSCALX +
 8   1.5000e-04   FRZ-4 * LPR-CCF-FT862ABX +
12   1.5000e-04   FRZ-4 * LPR-CCF-FT860ABX +
14   1.5000e-04   FRZ-4 * LPR-CCF-FT863ABX +
17   5.0000e-05   LPR-CCF-PGSUMPX * FRZ-4 +
     -----------
     14.3000e-04   P(fire adjacent to 4)=4.59e-02;
```

FREQUENCY = (4.59e-02) * (0.1) * (0.1) * (1.43e-03) * Q = 3.28e-11

SRY-FIRE-SEQ6-B =

SRY-FIRE-SEQ7-B =

SEQUENCE CUTSETS FOR SURRY FSS ROOT CAUSE 2

(AFTER SCREENING OUT CUTSETS WITHOUT RANDOM FAILURES
OR WITHOUT A FIRE ZONE OR WITH MORE THAN ONE FIRE ZONE)

(AFTER SCREENING OUT CUTSETS WITH FIRE ZONES 15, 19, 20)

ASSUMPTIONS: P(barrier failure) = 0.1; M = 4.0e-03; Q = 5.0e-05;
For Sequence 4, P(non-recovery)=4.4e-02 and ACP-XHE-FOSTBBSY=4.0E-03

SRY-FIRE-SEQ1 =

```
18   7.7000e-04    FRZ-2 * CPC-CCF-PG-STRAB +
55   7.0000e-05    FRZ-2 * HPI-CCF-FRCHABCX +
66   3.0000e-05    FRZ-2 * CPC-CCF-FRSWABX
     ----------
     8.7000e-04    P(fire in 2)=2.68e-03
       FREQUENCY = (2.68e-03) * (0.1) * (8.70e-04) * M = 9.33e-10

16   7.7000e-04    FRZ-4 * CPC-CCF-PG-STRAB +
53   7.0000e-05    FRZ-4 * HPI-CCF-FRCHABCX +
63   3.0000e-05    FRZ-4 * CPC-CCF-FRSWABX +
     ----------
     8.7000e-04    P(fire in 4)=2.97e-03
       FREQUENCY = (2.97e-03) * (0.1) * (8.70e-04) * M = 1.03e-09

 9   1.2000e-01    FRZ-31 * AFW-TDP-FR2P6HRX +
10   1.1000e-02    FRZ-31 * AFW-TDP-FSFW2X +
11   1.0000e-02    FRZ-31 * AFW-TDP-MAFW2X +
33   1.3000e-04    FRZ-31 * AFW-PSF-FCXCONNX +
34   1.0000e-04    AFW-CKV-FTCV142X * FRZ-31 +
42   9.0000e-05    AFW-CCF-LKSTMBDX * FRZ-31 +
59   4.0000e-05    FRZ-31 * AFW-XVM-PGXV153X +
     ----------
     1.4136e-01    P(fire in 31)=3.21e-02
       FREQUENCY = (3.21e-02) * (0.1) * (1.4136e-01) * M = 1.82e-06

32   1.3000e-04    AFW-PSF-FCXCONNX * FRZ-54 +
35   9.0000e-05    AFW-CCF-LKSTMBDX * FRZ-54 +
62   3.7200e-05    AFW-CCF-FSFW3ABX * AFW-TDP-FR2P6HRX * FRZ-54 +
     ----------
     2.5720e-04    P(fire in 54)= 3.71e-03
       FREQUENCY = (3.71e-03) * (0.1) * (2.572e-04) * M = 3.82e-10
```

SRY-FIRE-SEQ2 =

```
 4   1.5000e-04    FRZ-2 * HPI-CCF-FT115CEX +
 9   1.5000e-04    FRZ-2 * HPI-CCF-FT867CDX +
10   1.5000e-04    FRZ-2 * HPI-CCF-FT115BDX +
13   1.0000e-04    FRZ-2 * HPI-CKV-FTCV410X +
14   1.0000e-04    FRZ-2 * HPI-CKV-FTCV225X +
21   1.0000e-04    FRZ-2 * HPI-CKV-FTCV25X +
27   4.0000e-05    FRZ-2 * HPI-XVM-PGXV24X +
     ----------
     7.9000e-04    P(fire in 2)=2.68e-03
       FREQUENCY = (2.68e-03) * (0.1) * (7.90e-04) * M = 8.47e-10
```

```
 2   1.5000e-04    FRZ-4 * HPI-CCF-FTB67CDX +
 3   1.5000e-04    FRZ-4 * HPI-CCF-FT115BDX +
 8   1.5000e-04    FRZ-4 * HPI-CCF-FT115CEX +
16   1.0000e-04    FRZ-4 * HPI-CKV-FTCV25X +
19   1.0000e-04    FRZ-4 * HPI-CKV-FTCV410X +
23   1.0000e-04    FRZ-4 * HPI-CKV-FTCV225X +
26   4.0000e-05    FRZ-4 * HPI-XVM-PGXV24X +
     ----------
     7.9000e-04    P(fire in 4)=2.97e-03
       FREQUENCY = (2.97e-03) * (0.1) * (7.90e-04) * M = 9.39e-10


                   SRY-FIRE-SEQ3 =

 7   1.2000e-02    FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
11   1.2000e-02    FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
16   1.0000e-03    FRZ-2 * PPS-SOV-FT1455CX +
20   1.0000e-03    FRZ-2 * PPS-SOV-FT1456X +
23   6.0000e-04    FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
27   6.0000e-04    FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
30   9.0000e-05    FRZ-2 * DCP-BDC-STBUS1BX +
36   9.0000e-05    FRZ-2 * DCP-BDC-STBUS1AX +
42   7.0000e-05    FRZ-2 * PPS-CCF-FTPORVX +
54   2.7000e-05    FRZ-2 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
55   2.7000e-05    FRZ-2 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
56   2.7000e-05    FRZ-2 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
57   2.7000e-05    FRZ-2 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
65   2.7000e-05    FRZ-2 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
74   2.7000e-05    FRZ-2 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
85   1.2000e-05    FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +
92   1.2000e-05    FRZ-2 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
94   1.2000e-05    FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +
95   1.2000e-05    FRZ-2 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +
     ----------
     2.7660e-02    P(fire in 2)=2.68e-03
       FREQUENCY = (2.68e-03) * (0.1) * (2.766e-02) * M = 2.97e-08

 5   1.2000e-02    FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
10   1.2000e-02    FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
15   1.0000e-03    FRZ-4 * PPS-SOV-FT1456X +
19   1.0000e-03    FRZ-4 * PPS-SOV-FT1455CX +
22   6.0000e-04    FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
26   6.0000e-04    FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
32   9.0000e-05    FRZ-4 * DCP-BDC-STBUS1AX +
35   9.0000e-05    FRZ-4 * DCP-BDC-STBUS1BX +
40   7.0000e-05    FRZ-4 * PPS-CCF-FTPORVX +
52   2.7000e-05    FRZ-4 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
53   2.7000e-05    FRZ-4 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
65   2.7000e-05    FRZ-4 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
66   2.7000e-05    FRZ-4 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
68   2.7000e-05    FRZ-4 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
73   2.7000e-05    FRZ-4 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
87   1.2000e-05    FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +
89   1.2000e-05    FRZ-4 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
96   1.2000e-05    FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +
98   1.2000e-05    FRZ-4 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +
     ----------
     2.7660e-02    P(fire in 4)=2.97e-03
 FREQUENCY = (2.97e-03) * (0.1) * (2.766e-02) * M = 3.29e-08
```

```
                    SRY-FIRE-SEQ4 =

  6   4.0000e-03     FRZ-31 * ACP-XHE-FOSTBBSX +
 20   4.0000e-05     FRZ-31 * IAS-AOV-PGCC107X +
 22   2.0000e-05     FRZ-31 * IAS-AOV-LKCC107X +
 24   2.0000e-05     FRZ-31 * CCW-CCF-FRCC1ABX +
      ----------
      4.0800e-03     P(fire in 31)=3.21e-02
        FREQUENCY = (3.21e-02) * (0.1) * (4.08e-03) * (4.4e-02) = 5.76e-07

  7   9.6000e-04     CPC-MDP-FRSW10AX * FRZ-45 * ACP-XHE-FOSTBBSX +
  9   3.8000e-04     FRZ-45 * CPC-STR-PGSTR2AX * ACP-XHE-FOSTBBSX +
 12   1.8000e-04     FRZ-45 * CPC-STR-PGSTR1AX * ACP-XHE-FOSTBBSX +
 13   9.0000e-05     ACP-BAC-ST-1H11X * FRZ-45 * ACP-XHE-FOSTBBSX +
 14   9.0000e-05     ACP-BAC-ST4KV1HX * FRZ-45 * ACP-XHE-FOSTBBSX +
 15   9.0000e-05     ACP-BAC-ST1H1X * FRZ-45 * ACP-XHE-FOSTBBSX +
 19   4.0000e-05     ACP-TFM-NO1H1X * FRZ-45 * ACP-XHE-FOSTBBSX +
      ----------
      1.8300e-03     P(fire in 45) = 3.71e-03
   FREQUENCY = (3.71e-03) * (0.1) * (1.83e-03) * (4.0e-03) * (4.4e-02)
           = 1.19e-10

  3   4.0000e-03     FRZ-54 * ACP-XHE-FOSTBBSX +
 18   4.0000e-05     FRZ-54 * IAS-AOV-PGCC107X +
 23   2.0000e-05     FRZ-54 * CCW-CCF-FRCC1ABX +
 25   2.0000e-05     FRZ-54 * IAS-AOV-LKCC107X
      ----------
      4.0800e-03     P(fire in 54)= 3.71e-03
        FREQUENCY = (3.71e-03) * (0.1) * (4.08e-03) * (4.4e-02) = 6.66e-08


                SRY-FIRE-SEQ6 =

  7   9.6000e-04     CPC-MDP-FRSW10AX * FRZ-45 +
  9   3.8000e-04     FRZ-45 * CPC-STR-PGSTR2AX +
 12   1.8000e-04     FRZ-45 * CPC-STR-PGSTR1AX +
 19   9.0000e-05     ACP-BAC-ST-1H11X * FRZ-45 +
 20   9.0000e-05     ACP-BAC-ST4KV1HX * FRZ-45 +
 21   9.0000e-05     ACP-BAC-ST1H1X * FRZ-45 +
 24   4.0000e-05     ACP-TFM-NO1H1X * FRZ-45 +
     -----------
      1.8300e-03     P(fire in 45) = 3.71e-03
         FREQUENCY = (3.71e-03) * (0.1) * (1.83e-03) * Q = 3.39e-11


                    SRY-FIRE-SEQ7 =

  8   1.8000e-04     FRZ-2 * 3 RANDOM EVENTS +
 12   1.4400e-04     FRZ-2 * 4 RANDOM EVENTS +
 18   7.0000e-05     FRZ-2 * PPS-CCF-FTPORVX +
 24   1.2000e-05     FRZ-2 * 3 RANDOM EVENTS +
 27   1.2000e-05     FRZ-2 * 3 RANDOM EVENTS +
      ----------
      4.1800e-04     P(fire in 2)=2.68e-03
        FREQUENCY = (2.68e-03) * (0.1) * (4.18e-04) * Q = 5.60e-12

  5   1.8000e-04     FRZ-4 * 3 RANDOM EVENTS +
  9   1.4400e-04     FRZ-4 * 4 RANDOM EVENTS +
 15   7.0000e-05     FRZ-4 * PPS-CCF-FTPORVX +
 20   1.2000e-05     FRZ-4 * 3 RANDOM EVENTS +
 23   1.2000e-05     FRZ-4 * 3 RANDOM EVENTS +
```

```
        ----------
        4.1800e-04    P(fire in 4)=2.97e-03
          FREQUENCY = (2.97e-03) * (0.1) * (4.18e-04) * Q = 6.21e-12


                   SRY-FIRE-SEQ2-B =

  8     1.2000e-02    FRZ-2 * 3 RANDOM EVENTS +
 12     1.2000e-02    FRZ-2 * 3 RANDOM EVENTS +
 15     1.0000e-03    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
 19     1.0000e-03    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
 27     6.0000e-04    FRZ-2 * 3 RANDOM EVENTS +
 31     6.0000e-04    FRZ-2 * 3 RANDOM EVENTS +
 49     9.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
 53     9.0000e-05    DCP-BDC-STBUS1BX * FRZ-2 * LPR-XHE-FOHOTLGX +
 57     7.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
 78     2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 79     2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 80     2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 81     2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 89     2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
 91     2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
105     1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
109     1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
110     1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
112     1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
        ----------
        2.7660e-02    P(fire in 2)=2.68e-03
           FREQUENCY = (2.68e-03) * (0.1) * (2.766e-02) * M = 2.97e-08

  7     1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
 11     1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
 14     1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
 18     1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
 26     6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
 30     6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
 50     9.0000e-05    DCP-BDC-STBUS1BX * FRZ-4 * LPR-XHE-FOHOTLGX +
 52     9.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
 54     7.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
 73     2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 74     2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 76     2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 77     2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 88     2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 90     2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
106     1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
114     1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
115     1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
116     1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
        ----------
        2.7660e-02    P(fire in 4)=2.97e-03
         FREQUENCY = (2.97e-03) * (0.1) * (2.766e-02) * M = 3.29e-08


                   SRY-FIRE-SEQ3-B =

                   SRY-FIRE-SEQ4-B =

   4    1.0000e+00    FRZ-2 * LPR-XHE-FOHOTLGX +
                       P(fire in 2)=2.68e-03
           FREQUENCY = (2.68e-03) * (0.1) * (1.0e+00) * Q = 1.34e-08
```

```
  7   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +
 10   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +
 13   1.5000e-04    FRZ-2 * LPR-CCF-FT890ABX +
 14   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +
 18   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +
 23   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +
      ----------
      1.4300e-03    P(fire in 2)=2.68e-03
        FREQUENCY = (2.68e-03) * (0.1) * (1.43e-03) * Q = 1.92e-11

  1   1.0000e+00    FRZ-4 * LPR-XHE-FOHOTLGX +
                      P(fire in 4)=2.97e-03
     FREQUENCY = (2.97e-03) * (0.1) * (1.0e+00) * Q = 1.49e-08

  5   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +
  8   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +
 11   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +
 17   1.5000e-04    FRZ-4 * LPR-CCF-FT890ABX +
 19   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +
 24   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +
      ----------
      1.4300e-03    P(fire in 4)=2.97e-03
       FREQUENCY = (2.97e-03) * (0.1) * (1.43e-03) * Q = 2.12e-11

                      SRY-FIRE-SEQ5-B =

    4   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +
    7   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +
   10   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +
   13   1.5000e-04    FRZ-2 * LPR-CCF-FT863ABX +
   15   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +
   18   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +
        ----------
        1.4300e-03    P(fire in 2)=2.68e-03
   FREQUENCY = (2.68e-03) * (0.1) * (1.43e-03) * Q = 1.92e-11

    3   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +
    6   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +
    8   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +
   12   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +
   14   1.5000e-04    FRZ-4 * LPR-CCF-FT863ABX +
   17   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +
        ----------
        1.4300e-03    P(fire in 4)=2.97e-03
   FREQUENCY = (2.97e-03) * (0.1) * (1.43e-03) * Q = 2.12e-11

                      SRY-FIRE-SEQ6-B =

                      SRY-FIRE-SEQ7-B =
```

TABLE 4-D.
SEQUENCE CUTSETS FOR SURRY FSS ROOT CAUSE 4--HUMAN ERROR

(AFTER SCREENING IN ONLY CUTSETS WITH FIRE ZONES
CAPABLE OF BEING ACTUATED FROM ONE CONTROL PANEL)

(AFTER SCREENING OUT CUTSETS REQUIRING FSS DAMAGE IN ZONE 31)

ASSUMPTIONS: P(damage by FSS)=0.1, except in 6 and 8 where P(damage)=1.0
and FRZ-17 where P(damage)=0.001;
from LER data, frequency(human error FSS actuation)=0.06/rx-yr;
P(human error given fire)=0.1;

NOTE: Surry has 15 fire zones with suppression systems installed. Therefore, a factor of 1/15 (.0667) is included to divide the frequency of FSS actuation among the 15 areas.

SRY-FIRE-SEQ1 =

18	7.7000e-04	FRZ-2 * CPC-CCF-PG-STRAB +	LOCAL ERROR
55	7.0000e-05	FRZ-2 * HPI-CCF-FRCHABCX +	LOCAL ERROR
66	3.0000e-05	FRZ-2 * CPC-CCF-FRSWABX	LOCAL ERROR
	8.7000e-04		

FREQUENCY = (0.06) * (0.0667) * (0.1) * (8.70e-04) * M = 1.39e-09

16	7.7000e-04	FRZ-4 * CPC-CCF-PG-STRAB +
53	7.0000e-05	FRZ-4 * HPI-CCF-FRCHABCX +
63	3.0000e-05	FRZ-4 * CPC-CCF-FRSWABX +
	8.7000e-04	

FREQUENCY = (0.06) * (0.0667) * (0.1) * (8.70e-04) * M = 1.39e-09

SRY-FIRE-SEQ2 =

4	1.5000e-04	FRZ-2 * HPI-CCF-FT115CEX +	LOCAL ERROR
9	1.5000e-04	FRZ-2 * HPI-CCF-FT867CDX +	LOCAL ERROR
10	1.5000e-04	FRZ-2 * HPI-CCF-FT115BDX +	LOCAL ERROR
13	1.0000e-04	FRZ-2 * HPI-CKV-FTCV410X +	LOCAL ERROR
14	1.0000e-04	FRZ-2 * HPI-CKV-FTCV225X +	LOCAL ERROR
21	1.0000e-04	FRZ-2 * HPI-CKV-FTCV25X +	LOCAL ERROR
27	4.0000e-05	FRZ-2 * HPI-XVM-PGXV24X +	LOCAL ERROR
	7.9000e-04		

FREQUENCY = (0.06) * (0.0667) * (0.1) * (7.90e-04) * M = 1.26e-09

2	1.5000e-04	FRZ-4 * HPI-CCF-FT867CDX +
3	1.5000e-04	FRZ-4 * HPI-CCF-FT115BDX +
8	1.5000e-04	FRZ-4 * HPI-CCF-FT115CEX +
16	1.0000e-04	FRZ-4 * HPI-CKV-FTCV25X +
19	1.0000e-04	FRZ-4 * HPI-CKV-FTCV410X +
23	1.0000e-04	FRZ-4 * HPI-CKV-FTCV225X +
26	4.0000e-05	FRZ-4 * HPI-XVM-PGXV24X +
	7.9000e-04	

FREQUENCY = (0.06) * (0.0667) * (0.1) * (7.90e-04) * M = 1.26e-09

```
                         SRY-FIRE-SEQ3 =

  7   1.2000e-02     FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +  LOCAL ERROR
 11   1.2000e-02     FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +  LOCAL ERROR
 16   1.0000e-03     FRZ-2 * PPS-SOV-FT1455CX +              LOCAL ERROR
 20   1.0000e-03     FRZ-2 * PPS-SOV-FT1456X +               LOCAL ERROR
 23   6.0000e-04     FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +  LOCAL ERROR
 27   6.0000e-04     FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +  LOCAL ERROR
 30   9.0000e-05     FRZ-2 * DCP-BDC-STBUS1BX +             LOCAL ERROR
 36   9.0000e-05     FRZ-2 * DCP-BDC-STBUS1AX +             LOCAL ERROR
 42   7.0000e-05     FRZ-2 * PPS-CCF-FTPORVX +              LOCAL ERROR
 54   2.7000e-05     FRZ-2 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +  LOCAL ERROR
 55   2.7000e-05     FRZ-2 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +  LOCAL ERROR
 56   2.7000e-05     FRZ-2 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +  LOCAL ERROR
 57   2.7000e-05     FRZ-2 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +   LOCAL ERROR
 69   2.7000e-05     FRZ-2 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +   LOCAL ERROR
 74   2.7000e-05     FRZ-2 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +  LOCAL ERROR
 85   1.2000e-05     FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FG1536X +   LOCAL ERROR
 92   1.2000e-05     FRZ-2 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +    LOCAL ERROR
 94   1.2000e-05     FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FG1535X +   LOCAL ERROR
 95   1.2000e-05     FRZ-2 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +    LOCAL ERROR

      ----------
      2.7660e-02
   FREQUENCY = (0.06) * (0.0667) * (0.1) * (2.766e-02) * M = 4.43e-08

--------------------
  6   1.2000e-02     FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
 10   1.2000e-02     FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
 15   1.0000e-03     FRZ-4 * PPS-SOV-FT1456X +
 19   1.0000e-03     FRZ-4 * PPS-SOV-FT1455CX +
 22   6.0000e-04     FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
 26   6.0000e-04     FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
 32   9.0000e-05     FRZ-4 * DCP-BDC-STBUS1AX +
 35   9.0000e-05     FRZ-4 * DCP-BDC-STBUS1BX +
 40   7.0000e-05     FRZ-4 * PPS-CCF-FTPORVX +
 52   2.7000e-05     FRZ-4 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
 53   2.7000e-05     FRZ-4 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
 65   2.7000e-05     FRZ-4 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
 66   2.7000e-05     FRZ-4 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
 68   2.7000e-05     FRZ-4 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
 73   2.7000e-05     FRZ-4 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
 87   1.2000e-05     FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FG1536X +
 89   1.2000e-05     FRZ-4 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
 96   1.2000e-05     FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FG1535X +
 98   1.2000e-05     FRZ-4 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +

      ----------
      2.7660e-02
   FREQUENCY = (0.06) * (0.0667) * (0.1) * (2.766e-02) * M = 4.43e-08

--------------------
  46   6.0000e-05     FRZ-4 * LOSPX * FRZ-8 * PPS-MOV-FC1536X +
  79   2.7000e-05     FRZ-4 * FRZ-8 * OEP-BAC-STFDRDX * PPS-MOV-FC1536X +

       ----------
       8.7000e-05     P(fire in 4)=2.97e-03; P(fire in 8)=2.31e-02
   FREQUENCY = [(2.31e-02) * (0.1) * (0.1) + (2.97e-03) * (0.1) * (1.0)]
               * (8.7e-05) * M = 1.84e-10

                         SRY-FIRE-SEQ4 =

  1   1.0000e+00     FRZ-1 +                              LOCAL ERROR
 FREQUENCY = (0.06) * (0.0667) * (0.1) * (4.4e-02) = 1.76e-05
```

```
---------------------
   2   1.0000e+00     FRZ-3 +
  FREQUENCY = (0.06) * (0.0667) * (0.1) * (4.4e-02) = 1.76e-05

---------------------
   4   1.0000e+00     FRZ-17 +
  FREQUENCY = (0.06) * (0.0667) * (0.001) * (4.4e-02) = 1.76e-07

---------------------
  10   2.0000e-04     LOSPX * FRZ-6 * FRZ-8 +
                      P(fire in 6) = P(fire in 8) = 2.31e-02
     FREQUENCY = [(2.31e-02) * (0.1) * (1.0) + (2.31e-02) * (0.1) * (1.0)]
                 * (2.0e-04) * (4.4e-02) = 4.07e-08


                    SRY-FIRE-SEQ6 =

   4   1.0000e+00     FRZ-17 +
    FREQUENCY = (0.06) * (0.0667) * (0.001) * Q = 2.0e-10

---------------------                                   LOCAL ERROR
   5   1.0000e+00     FRZ-1 +
    FREQUENCY = (0.06) * (0.0667) * (0.1) * Q = 2.0e-08

---------------------
   6   1.0000e+00     FRZ-3 +
    FREQUENCY = (0.06) * (0.0667) * (0.1) * Q = 2.0e-08

---------------------
  11   2.0000e-04     LOSPX * FRZ-6 * FRZ-8 +
                      P(fire in 6) = P(fire in 8) = 2.31e-02
     FREQUENCY = [(2.31e-02) * (0.1) * (1.0) + (2.31e-02) * (0.1) * (1.0)]
                 * (2.0e-04) * Q = 4.62e-11


                    SRY-FIRE-SEQ7 =

   8   1.8000e-04     FRZ-2 * 3 RANDOM EVENTS +          LOCAL ERROR
  12   1.4400e-04     FRZ-2 * 4 RANDOM EVENTS +          LOCAL ERROR
  18   7.0000e-05     FRZ-2 * PPS-CCF-FTPORVX +          LOCAL ERROR
  24   1.2000e-05     FRZ-2 * 3 RANDOM EVENTS +          LOCAL ERROR
  27   1.2000e-05     FRZ-2 * 3 RANDOM EVENTS +          LOCAL ERROR
       ----------
       4.1800e-04
    FREQUENCY = (0.06) * (0.0667) * (0.1) * (4.18e-04) * Q = 8.36e-12

---------------------
   5   1.8000e-04     FRZ-4 * 3 RANDOM EVENTS +
   9   1.4400e-04     FRZ-4 * 4 RANDOM EVENTS +
  15   7.0000e-05     FRZ-4 * PPS-CCF-FTPORVX +
  20   1.2000e-05     FRZ-4 * 3 RANDOM EVENTS +
  23   1.2000e-05     FRZ-4 * 3 RANDOM EVENTS +
       ----------
       4.1800e-04
    FREQUENCY = (0.06) * (0.0667) * (0.1) * (4.18e-04) * Q = 8.36e-12


                    SRY-FIRE-SEQ2-B =

   8   1.2000e-02     FRZ-2 * 3 RANDOM EVENTS +                       LOCAL ERROR
  12   1.2000e-02     FRZ-2 * 3 RANDOM EVENTS +                       LOCAL ERROR
  15   1.0000e-03     FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +   LOCAL ERROR
  19   1.0000e-03     FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +    LOCAL ERROR
  27   6.0000e-04     FRZ-2 * 3 RANDOM EVENTS +                       LOCAL ERROR
  31   6.0000e-04     FRZ-2 * 3 RANDOM EVENTS +                       LOCAL ERROR
  49   9.0000e-05     FRZ-2 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +   LOCAL ERROR
  53   9.0000e-05     DCP-BDC-STBUS1BX * FRZ-2 * LPR-XHE-FOHOTLGX +   LOCAL ERROR
```

```
 57   7.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +    LOCAL ERROR
 78   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
 79   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
 80   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
 81   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
 89   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
 91   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
105   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
109   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR
110   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS  +                  LOCAL ERROR
112   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +                   LOCAL ERROR

      ----------
      2.7660e-02
      FREQUENCY = (0.06) * (0.0667) * (0.1) * (2.766e-02) * M = 4.43e-08

--------------------
  7   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
 11   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
 14   1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
 18   1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
 26   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
 30   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
 50   9.0000e-05    DCP-BDC-STBUS1BX * FRZ-4 * LPR-XHE-FOHOTLGX +
 52   9.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
 54   7.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
 73   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 74   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 76   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 77   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 88   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 90   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
106   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
114   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
115   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
116   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +

      ----------
      2.7660e-02
      FREQUENCY = (0.06) * (0.0667) * (0.1) * (2.766e-02) * M = 4.43e-08

----------------------
 63   6.0000e-05    LOSPX * FRZ-8 * FRZ-4 * 2 OTHER RANDOM EVENTS +
 99   2.7000e-05    FRZ-8 * FRZ-4 * 3 RANDOM EVENTS +

      ----------
      8.7000e-05    P(fire in 4)=2.97e-03; P(fire in 8)=2.31e-02
      FREQUENCY = [(2.31e-02) * (0.1) * (0.1) + (2.97e-03) * (0.1) * (1.0)]
                  * (8.7e-05) * M = 1.84e-10


                    SRY-FIRE-SEC3-B =

                    SRY-FIRE-SEC4-B =

                                                                  LOCAL ERROR
  4   1.0000e+00    FRZ-2 * LPR-XHE-FOHOTLGX +
      FREQUENCY = (0.06) * (0.0667) * (0.1) * Q = 2.0e-08

------------------
  7   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +                  LOCAL ERROR
 10   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +                  LOCAL ERROR
 13   1.5000e-04    FRZ-2 * LPR-CCF-FT890ABX +                  LOCAL ERROR
 14   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +                  LOCAL ERROR
 18   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +                  LOCAL ERROR
 23   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +                   LOCAL ERROR

      -----------
      14.3000e-04
```

FREQUENCY = (0.06) * (0.0667) * (0.1) * (1.43e-03) * D = 2.86e-11

```
   1   1.0000e+00    FRZ-4 * LPR-XHE-FOHOTLGX +
  FREQUENCY = (0.06) * (0.0667) * (0.1) * Q = 2.0e-08
---------------------
   5   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +
   8   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +
  11   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +
  17   1.5000e-04    FRZ-4 * LPR-CCF-FT890ABX +
  19   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +
  24   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +
      -----------
      14.3000e-04
  FREQUENCY = (0.06) * (0.0667) * (0.1) * (1.43e-03) * D = 2.86e-11


                    SRY-FIRE-SEQ5-B =

   4   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +        LOCAL ERROR
   7   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +        LOCAL ERROR
  10   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +        LOCAL ERROR
  13   1.5000e-04    FRZ-2 * LPR-CCF-FT863ABX +        LOCAL ERROR
  15   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +        LOCAL ERROR
  18   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +         LOCAL ERROR
      -----------
      14.3000e-04
  FREQUENCY = (0.06) * (0.0667) * (0.1) * (1.43e-03) * D = 2.86e-11
---------------------
   3   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +
   6   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +
   8   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +
  12   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +
  14   1.5000e-04    FRZ-4 * LPR-CCF-FT863ABX +
  17   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +
      -----------
      14.3000e-04
  FREQUENCY = (0.06) * (0.0667) * (0.1) * (1.43e-03) * D = 2.86e-11


                    SRY-FIRE-SEQ6-B =

                    SRY-FIRE-SEQ7-B =
```

TABLE 4-E.
SEQUENCE CUTSETS FOR SURRY FSS ROOT CAUSE 5

(AFTER SCREENING IN CUTSETS HAVING FIRE ZONES WITH STEAM PIPES OR ADJACENT TO AREAS WITH STEAM PIPES)

(AFTER SCREENING OUT CUTSETS REQUIRING FSS DAMAGE IN ZONE 31)

ASSUMPTIONS FOR PROBABILITY SCREENING: P(FSS damage[except in 6 or 8])=0.1;
P(FSS damage in 17)=0.001; P(steam pipe break)=0.003;
P(steam penetrates barrier to other area)=0.1

SRY-FIRE-SEQ1 =

18	7.7000e-04	FRZ-2 * CPC-CCF-PG-STRAB +	STEAM IN 17
55	7.0000e-05	FRZ-2 * HPI-CCF-FRCHABCX +	STEAM IN 17
66	3.0000e-05	FRZ-2 * CPC-CCF-FRSWABX	STEAM IN 17
	8.7000e-04		

FREQUENCY = (0.003) * (0.1) * (0.1) * (8.7e-04) * M = 1.04e-10

16	7.7000e-04	FRZ-4 * CPC-CCF-PG-STRAB +	STEAM IN 31
53	7.0000e-05	FRZ-4 * HPI-CCF-FRCHABCX +	STEAM IN 31
63	3.0000e-05	FRZ-4 * CPC-CCF-FRSWABX +	STEAM IN 31
	8.7000e-04		

FREQUENCY = (0.003) * (0.1) * (0.1) * (8.7e-04) * M = 1.04e-10

SRY-FIRE-SEQ2 =

4	1.5000e-04	FRZ-2 * HPI-CCF-FT115CEX +	STEAM IN 17
9	1.5000e-04	FRZ-2 * HPI-CCF-FT867CDX +	STEAM IN 17
10	1.5000e-04	FRZ-2 * HPI-CCF-FT115BDX +	STEAM IN 17
13	1.0000e-04	FRZ-2 * HPI-CKV-FTCV410X +	STEAM IN 17
14	1.0000e-04	FRZ-2 * HPI-CKV-FTCV225X +	STEAM IN 17
21	1.0000e-04	FRZ-2 * HPI-CKV-FTCV25X +	STEAM IN 17
27	4.0000e-05	FRZ-2 * HPI-XVM-PGXV24X +	STEAM IN 17
	7.9000e-04		

FREQUENCY = (0.003) * (0.1) * (0.1) * (7.9e-04) * M = 9.48e-11

2	1.5000e-04	FRZ-4 * HPI-CCF-FT867CDX +	STEAM IN 31
3	1.5000e-04	FRZ-4 * HPI-CCF-FT115BDX +	STEAM IN 31
8	1.5000e-04	FRZ-4 * HPI-CCF-FT115CEX +	STEAM IN 31
16	1.0000e-04	FRZ-4 * HPI-CKV-FTCV25X +	STEAM IN 31
19	1.0000e-04	FRZ-4 * HPI-CKV-FTCV410X +	STEAM IN 31
23	1.0000e-04	FRZ-4 * HPI-CKV-FTCV225X +	STEAM IN 31
26	4.0000e-05	FRZ-4 * HPI-XVM-PGXV24X +	STEAM IN 31
	7.9000e-04		

FREQUENCY = (0.003) * (0.1) * (0.1) * (7.9e-04) * M = 9.48e-11

SRY-FIRE-SEQ3 =

7	1.2000e-02	FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +	STEAM IN 17
11	1.2000e-02	FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +	STEAM IN 17

```
 16   1.0000e-03    FRZ-2 * PPS-SOV-FT1455CX +                       STEAM IN 17
 20   1.0000e-03    FRZ-2 * PPS-SOV-FT1456X +                        STEAM IN 17
 23   6.0000e-04    FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +   STEAM IN 17
 27   6.0000e-04    FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +   STEAM IN 17
 30   9.0000e-05    FRZ-2 * DCP-BDC-STBUS1BX +                     STEAM IN 17
 36   9.0000e-05    FRZ-2 * DCP-BDC-STBUS1AX +                     STEAM IN 17
 42   7.0000e-05    FRZ-2 * PPS-CCF-FTPORVX +                      STEAM IN 17
 54   2.7000e-05    FRZ-2 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +   STEAM IN 17
 55   2.7000e-05    FRZ-2 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +   STEAM IN 17
 56   2.7000e-05    FRZ-2 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +   STEAM IN 17
 57   2.7000e-05    FRZ-2 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +     STEAM IN 17
 69   2.7000e-05    FRZ-2 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +     STEAM IN 17
 74   2.7000e-05    FRZ-2 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +   STEAM IN 17
 85   1.2000e-05    FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FG1536X +    STEAM IN 17
 92   1.2000e-05    FRZ-2 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +     STEAM IN 17
 94   1.2000e-05    FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FG1535X +    STEAM IN 17
 95   1.2000e-05    FRZ-2 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +     STEAM IN 17

      -----------
      2.7660e-02
   FREQUENCY = (0.003) * (0.1) * (0.1) * (2.766e-02) * M = 3.32e-09

--------------------------  FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +   STEAM IN 31
  6   1.2000e-02    FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +   STEAM IN 31
 10   1.2000e-02    FRZ-4 * PPS-SOV-FT1456X +                     STEAM IN 31
 15   1.0000e-03    FRZ-4 * PPS-SOV-FT1455CX +                    STEAM IN 31
 19   1.0000e-03    FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +   STEAM IN 31
 22   6.0000e-04    FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +   STEAM IN 31
 26   6.0000e-04    FRZ-4 * DCP-BDC-STBUS1AX +                    STEAM IN 31
 32   9.0000e-05    FRZ-4 * DCP-BDC-STBUS1BX +                    STEAM IN 31
 35   9.0000e-05    FRZ-4 * PPS-CCF-FTPORVX +                     STEAM IN 31
 40   7.0000e-05    FRZ-4 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +   STEAM IN 31
 52   2.7000e-05    FRZ-4 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +     STEAM IN 31
 53   2.7000e-05    FRZ-4 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +   STEAM IN 31
 65   2.7000e-05    FRZ-4 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +   STEAM IN 31
 66   2.7000e-05    FRZ-4 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +   STEAM IN 31
 68   2.7000e-05    FRZ-4 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +     STEAM IN 31
 73   2.7000e-05    FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FG1536X +    STEAM IN 31
 87   1.2000e-05    FRZ-4 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +     STEAM IN 31
 89   1.2000e-05    FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FG1535X +    STEAM IN 31
 96   1.2000e-05    FRZ-4 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +     STEAM IN 31
 98   1.2000e-05

      -----------
      2.7660e-02
   FREQUENCY = (0.003) * (0.1) * (0.1) * (2.766e-02) * M = 3.32e-09

------------------------- FRZ-6 *DEP-BAC-STFDRFX *PPS-MOV-FC1535X +   STEAM IN 31
 78   2.70e-05  FRZ-4 * 
 45   6.0000e-05    FRZ-4 * LOSPX * FRZ-6 * PPS-MOV-FC1535X +    STEAM IN 31

      -----------
      8.7000e-05
     FREQUENCY = (0.003) * (0.1) * (0.1) * (0.1) * (1.0) * (8.7e-05) * M
               = 1.04e-12

------------------------- FRZ-8 *DEP-BAC-STFDRDX *PPS-MOV-FC1536X +   STEAM IN 31
 79   2.70e-05  FRZ-4 * 
 46   6.0000e-05    FRZ-4 * LOSPX * FRZ-8 * PPS-MOV-FC1536X +    STEAM IN 31

      -----------
      8.7000e-05
     FREQUENCY = (0.003) * (0.1) * (0.1) * (0.1) * (1.0) * (8.7e-05) * M
               = 1.04e-12


                    SRY-FIRE-SEQ4 =
```

4 1.0000e+00 FRZ-17 + STEAM IN 17
FREQUENCY = (0.003) * (0.001) = 3.00e-06

---

1 1.0000e+00 FRZ-1 + STEAM IN 17
FREQUENCY = (0.003) * (0.1) * (0.1) = 3.00e-05

---

10 2.0000e-04 LOSPX * FRZ-6 * FRZ-8 + STEAM IN 31
FREQUENCY = (0.003) * (0.1) * (1.0) * (0.1) * (1.0) * (2.0e-04) * (4.4e-02)
= 2.64e-10

SRY-FIRE-SEQ6 =

4 1.0000e+00 FRZ-17 + STEAM IN 17
FREQUENCY = (0.003) * (0.001) * Q = 1.5e-10

---

5 1.0000e+00 FRZ-1 + STEAM IN 17
FREQUENCY = (0.003) * (0.1) * (0.1) * Q = 1.5e-09

---

11 2.0000e-04 LOSPX * FRZ-6 * FRZ-8 + STEAM IN 31
FREQUENCY = (0.003) * (0.1) * (1.0) * (0.1) * (1.0) * (2.0e-04) * Q
= 3.0e-13

SRY-FIRE-SEQ7 =

8	1.8000e-04	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
12	1.4400e-04	FRZ-2 * 4 RANDOM EVENTS +	STEAM IN 17
16	7.0000e-05	FRZ-2 * PPS-CCF-FTPORVX +	STEAM IN 17
24	1.2000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
27	1.2000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17

4.1800e-04
FREQUENCY = (0.003) * (0.1) * (0.1) * (4.18e-04) * Q = 6.27e-13

5	1.8000e-04	FRZ-4 * 3 RANDOM EVENTS +	STEAM IN 31
9	1.4400e-04	FRZ-4 * 4 RANDOM EVENTS +	STEAM IN 31
15	7.0000e-05	FRZ-4 * PPS-CCF-FTPORVX +	STEAM IN 31
20	1.2000e-05	FRZ-4 * 3 RANDOM EVENTS +	STEAM IN 31
23	1.2000e-05	FRZ-4 * 3 RANDOM EVENTS +	STEAM IN 31

4.1800e-04
FREQUENCY = (0.003) * (0.1) * (0.1) * (4.18e-04) * Q = 6.27e-13

SRY-FIRE-SEQ2-B =

8	1.2000e-02	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
12	1.2000e-02	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
15	1.000e-03	FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +	STEAM IN 17
19	1.000e-03	FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +	STEAM IN 17
27	6.0000e-04	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
31	6.0000e-04	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
49	9.000e-05	FRZ-2 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +	STEAM IN 17
53	9.000e-05	DCP-BDC-STBUS1BX * FRZ-2 * LPR-XHE-FOHOTLGX +	STEAM IN 17
57	7.000e-05	FRZ-2 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +	STEAM IN 17
78	2.7000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
79	2.7000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
80	2.7000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
81	2.7000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17
89	2.7000e-05	FRZ-2 * 3 RANDOM EVENTS +	STEAM IN 17

```
 91   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +                  STEAM IN 17
105   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +                  STEAM IN 17
109   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +                  STEAM IN 17
110   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS  +                 STEAM IN 17
112   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +                  STEAM IN 17

      -----------
      2.7660e-02
   FREQUENCY = (0.003) * (0.1) * (0.1) * (2.766e-02) * M = 3.32e-09

----------------------
  7   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +                          STEAM IN 31
 11   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +                          STEAM IN 31
 14   1.000e-03   FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +         STEAM IN 31
 18   1.000e-03   FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +        STEAM IN 31
 26   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +                          STEAM IN 31
 30   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +                          STEAM IN 31
 50   9.000e-05   DCP-BDC-STBUS1BX * FRZ-4 * LPR-XHE-FOHOTLGX +        STEAM IN 31
 52   9.000e-05   FRZ-4 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +        STEAM IN 31
 54   7.000e-05   FRZ-4 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +         STEAM IN 31
 73   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
 74   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
 76   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
 77   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
 88   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
 90   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
106   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
114   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
115   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31
116   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +                    STEAM IN 31

      -----------
      2.7660e-02
   FREQUENCY = (0.003) * (0.1) * (0.1) * (2.766e-02) * M = 3.32e-09

-------------------------
 62  6.000e-05  LOSPX * FRZ-6 * FRZ-4 * 2 OTHER RANDOM EVENTS +  STEAM IN 31
 98  2.7000e-05    FRZ-6 * FRZ-4 * 3 RANDOM EVENTS +         STEAM IN 31

     -----------
     8.7000e-05
  FREQUENCY = (0.003) * (0.1) * (0.1) * (0.1) * (1.0) * (8.7e-05) * M
            = 1.04e-12

-------------------------
 63  6.000e-05  LOSPX * FRZ-8 * FRZ-4 * 2 OTHER RANDOM EVENTS +  STEAM IN 31
 99  2.7000e-05    FRZ-8 * FRZ-4 * 3 RANDOM EVENTS +         STEAM IN 31

     -----------
     8.7000e-05
  FREQUENCY = (0.003) * (0.1) * (0.1) * (0.1) * (1.0) * (8.7e-05) * M
            = 1.04e-12


                    SRY-FIRE-SEQ3-B =

                    SRY-FIRE-SEQ4-B =

  4   1.0000e+00    FRZ-2 * LPR-XHE-FOHOTLGX +              STEAM IN 17
   FREQUENCY = (0.003) * (0.1) * (0.1) * Q = 1.5e-09

-------------------------
  7   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +              STEAM IN 17
 10   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +              STEAM IN 17
 13   1.5000e-04    FRZ-2 * LPR-CCF-FT890ABX +              STEAM IN 17
 14   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +              STEAM IN 17
 18   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +              STEAM IN 17
 23   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +               STEAM IN 17

      -----------
```

```
      1.4300e-03
     FREQUENCY = (0.003) * (0.1) * (0.1) * (1.43e-03) * Q = 2.15e-12

-----------------------
    1   1.0000e+00    FRZ-4 * LPR-XHE-FOHOTLGX +               STEAM IN 31
     FREQUENCY = (0.003) * (0.1) * (0.1) * Q = 1.5e-09

-----------------------
    5   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +               STEAM IN 31
    8   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +               STEAM IN 31
   11   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +               STEAM IN 31
   17   1.5000e-04    FRZ-4 * LPR-CCF-FT890ABX +               STEAM IN 31
   19   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +               STEAM IN 31
   24   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +                STEAM IN 31
       -----------
      1.4300e-03
     FREQUENCY = (0.003) * (0.1) * (0.1) * (1.43e-03) * Q = 2.15e-12


                     SRY-FIRE-SEQ5-B =

      4   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +           STEAM IN 17
      7   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +           STEAM IN 17
     10   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +           STEAM IN 17
     13   1.5000e-04    FRZ-2 * LPR-CCF-FT863ABX +           STEAM IN 17
     15   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +           STEAM IN 17
     18   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +            STEAM IN 17
         -----------
        1.4300e-03
     FREQUENCY = (0.003) * (0.1) * (0.1) * (1.43e-03) * Q = 2.15e-12

-----------------------
      3   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +             STEAM IN 31
      6   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +             STEAM IN 31
      8   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +             STEAM IN 31
     12   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +             STEAM IN 31
     14   1.5000e-04    FRZ-4 * LPR-CCF-FT863ABX +             STEAM IN 31
     17   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +              STEAM IN 31
         -----------
        1.4300e-03
     FREQUENCY = (0.003) * (0.1) * (0.1) * (1.43e-03) * Q = 2.15e-12


                      SRY-FIRE-SEQ6-B =

                      SRY-FIRE-SEQ7-B =
```

TABLE 4-F.
SEQUENCE CUTSETS FOR SURRY FSS ROOT CAUSE 6--FSS FAILURE

(AFTER SCREENING OUT CUTSETS THAT HAVE A FIRE ZONE WITHOUT FSS AND CUTSETS WITH MORE THAN ONE FIRE ZONE)

(AFTER SCREENING OUT CUTSETS REQUIRING DAMAGE IN ZONE 31)

ASSUMPTIONS: P(damage by FSS)=0.1 except in FRZ-6 & 8 where P(damage)=1.0 and FRZ-17 where P(damage)=0.001;

NOTE: From the LER database, the frequency of failure of water FSS's is 0.025/rx-yr, of carbon dioxide FSS's is 0.0077/rx-yr, and of halon FSS's is 0.0019/rx-yr. Since Surry has 6 water FSS's, 19 CO2 FSS's, and 4 halon FSS's, the frequency of FSS actuation due to FSS component failure on a per system basis is roughly 0.0042/sys-yr for water, 0.00040/sys-yr for CO2, and 0.00048/sys-yr for halon.

Note that fire areas 1, 2, and 17 have multiple systems. For these areas, the frequency of failure of each system were summed to obtain the frequency of FSS failure in the fire area. (For all three, frequency = 0.0050.)

SRY-FIRE-SEQ1 =

```
 18   7.7000e-04    FRZ-2 * CPC-CCF-PG-STRAB +
 55   7.0000e-05    FRZ-2 * HPI-CCF-FRCHABCX +
 66   3.0000e-05    FRZ-2 * CPC-CCF-FRSWABX
      ----------
      8.7000e-04
   FREQUENCY = (0.005) * (0.1) * (8.70e-04) * M = 1.74e-09
--------------------------
 16   7.7000e-04    FRZ-4 * CPC-CCF-PG-STRAB +
 53   7.0000e-05    FRZ-4 * HPI-CCF-FRCHABCX +
 63   3.0000e-05    FRZ-4 * CPC-CCF-FRSWABX +
      ----------
      8.7000e-04
   FREQUENCY = (0.00048) * (0.1) * (8.70e-04) * M = 1.67e-10
```

SRY-FIRE-SEQ2 =

```
  4   1.5000e-04    FRZ-2 * HPI-CCF-FT115CEX +
  9   1.5000e-04    FRZ-2 * HPI-CCF-FT867CDX +
 10   1.5000e-04    FRZ-2 * HPI-CCF-FT115BDX +
 13   1.0000e-04    FRZ-2 * HPI-CKV-FTCV410X +
 14   1.0000e-04    FRZ-2 * HPI-CKV-FTCV225X +
 21   1.0000e-04    FRZ-2 * HPI-CKV-FTCV25X +
 27   4.0000e-05    FRZ-2 * HPI-XVM-PGXV24X +
      ----------
      7.9000e-04
   FREQUENCY = (0.005) * (0.1) * (7.90e-04) * M = 1.58e-09
--------------------------
  2   1.5000e-04    FRZ-4 * HPI-CCF-FT867CDX +
  3   1.5000e-04    FRZ-4 * HPI-CCF-FT115BDX +
  8   1.5000e-04    FRZ-4 * HPI-CCF-FT115CEX +
 16   1.0000e-04    FRZ-4 * HPI-CKV-FTCV25X +
```

19	1.0000e-04	FRZ-4 * HPI-CKV-FTCV410X +
23	1.0000e-04	FRZ-4 * HPI-CKV-FTCV225X +
26	4.0000e-05	FRZ-4 * HPI-XVM-PGXV24X +

	7.9000e-04	

FREQUENCY = (0.00048) * (0.1) * (7.90e-04) * M = 1.52e-10

SRY-FIRE-SEQ3 =

7	1.2000e-02	FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
11	1.2000e-02	FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
16	1.0000e-03	FRZ-2 * PPS-SOV-FT1455CX +
20	1.0000e-03	FRZ-2 * PPS-SOV-FT1456X +
23	6.0000e-04	FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
27	6.0000e-04	FRZ-2 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
30	9.0000e-05	FRZ-2 * DCP-BDC-STBUS1BX +
36	9.0000e-05	FRZ-2 * DCP-BDC-STBUS1AX +
42	7.0000e-05	FRZ-2 * PPS-CCF-FTPORVX +
54	2.7000e-05	FRZ-2 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
55	2.7000e-05	FRZ-2 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
56	2.7000e-05	FRZ-2 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
57	2.7000e-05	FRZ-2 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
69	2.7000e-05	FRZ-2 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
74	2.7000e-05	FRZ-2 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
85	1.2000e-05	FRZ-2 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +
92	1.2000e-05	FRZ-2 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
94	1.2000e-05	FRZ-2 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +
95	1.2000e-05	FRZ-2 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +

	2.7660e-02	

FREQUENCY = (0.005) * (0.1) * (2.766e-02) * M = 5.53e-08

6	1.2000e-02	FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-FT1535X +
10	1.2000e-02	FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-FT1536X +
15	1.0000e-03	FRZ-4 * PPS-SOV-FT1456X +
19	1.0000e-03	FRZ-4 * PPS-SOV-FT1455CX +
22	6.0000e-04	FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1536X +
26	6.0000e-04	FRZ-4 * PPS-CCF-FT15356X * PPS-MOV-FC1535X +
32	9.0000e-05	FRZ-4 * DCP-BDC-STBUS1AX +
35	9.0000e-05	FRZ-4 * DCP-BDC-STBUS1BX +
40	7.0000e-05	FRZ-4 * PPS-CCF-FTPORVX +
52	2.7000e-05	FRZ-4 * ACP-BAC-ST4KV1JX * PPS-MOV-FC1536X +
53	2.7000e-05	FRZ-4 * ACP-BAC-ST1J1X * PPS-MOV-FC1536X +
65	2.7000e-05	FRZ-4 * ACP-BAC-ST-1H12X * PPS-MOV-FC1535X +
66	2.7000e-05	FRZ-4 * ACP-BAC-ST4KV1HX * PPS-MOV-FC1535X +
68	2.7000e-05	FRZ-4 * ACP-BAC-ST-1J12X * PPS-MOV-FC1536X +
73	2.7000e-05	FRZ-4 * ACP-BAC-ST1H1X * PPS-MOV-FC1535X +
87	1.2000e-05	FRZ-4 * PPS-MOV-FC1536X * PPS-MOV-PG1536X +
89	1.2000e-05	FRZ-4 * ACP-TFM-NO1H1X * PPS-MOV-FC1535X +
96	1.2000e-05	FRZ-4 * PPS-MOV-FC1535X * PPS-MOV-PG1535X +
98	1.2000e-05	FRZ-4 * ACP-TFM-NO1J1X * PPS-MOV-FC1536X +

	2.7660e-02	

FREQUENCY = (0.00048) * (0.1) * (2.766e-02) * M = 5.31e-09

CO_2

SRY-FIRE-SEQ4 =

1	1.0000e+00	FRZ-1 +

FREQUENCY = (0.005) * (0.1) * (4.4e-02) = 2.20e-05

```
----------------------------
     2   1.0000e+00    FRZ-3 +
         FREQUENCY = (0.00048) * (0.1) * (4.4e-02) = 2.11e-06

----------------------------
     4   1.0000e+00    FRZ-17 +
         FREQUENCY = (0.005) * (0.001) * (4.4e-02) = 2.20e-07


                SRY-FIRE-SEQ6 =

     4   1.0000e+00    FRZ-17 +
         FREQUENCY = (0.005) * (0.001) * Q = 2.5e-10

----------------------------
     5   1.0000e+00    FRZ-1 +
         FREQUENCY = (0.005) * (0.1) * Q = 2.5e-08

----------------------------
     6   1.0000e+00    FRZ-3 +
         FREQUENCY = (0.00048) * (0.1) * Q = 2.4e-09


                     SRY-FIRE-SEQ7 =

     8   1.8000e-04    FRZ-2 * 3 RANDOM EVENTS +
    12   1.4400e-04    FRZ-2 * 4 RANDOM EVENTS +
    18   7.0000e-05    FRZ-2 * PPS-CCF-FTPORVX +
    24   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
    27   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +

        -----------
         4.1800e-04
         FREQUENCY = (0.005) * (0.1) * (4.18e-04) * Q = 1.05e-11

----------------------------
     5   1.8000e-04    FRZ-4 * 3 RANDOM EVENTS +
     9   1.4400e-04    FRZ-4 * 4 RANDOM EVENTS +
    15   7.0000e-05    FRZ-4 * PPS-CCF-FTPORVX +
    20   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
    23   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +

        -----------
         4.1800e-04
         FREQUENCY = (0.00048) * (0.1) * (4.18e-04) * Q = 1.00e-12


                   SRY-FIRE-SEQ2-B =

     8   1.2000e-02    FRZ-2 * 3 RANDOM EVENTS +
    12   1.2000e-02    FRZ-2 * 3 RANDOM EVENTS +
    15   1.0000e-03    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
    19   1.0000e-03    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
    27   6.0000e-04    FRZ-2 * 3 RANDOM EVENTS +
    31   6.0000e-04    FRZ-2 * 3 RANDOM EVENTS +
    49   9.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
    53   9.0000e-05    DCP-BDC-STBUS1BX * FRZ-2 * LPR-XHE-FOHOTLGX +
    57   7.0000e-05    FRZ-2 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
    78   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
    79   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
    80   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
    81   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
    89   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
    91   2.7000e-05    FRZ-2 * 3 RANDOM EVENTS +
   105   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
   109   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
   110   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
```

```
 112   1.2000e-05    FRZ-2 * 3 RANDOM EVENTS +
       ----------
       2.7660e-02
          FREQUENCY = (0.005) * (0.1) * (2.766e-02) * M = 5.53e-08

------------------------
   7   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
  11   1.2000e-02    FRZ-4 * 3 RANDOM EVENTS +
  14   1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1456X +
  18   1.0000e-03    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-SOV-FT1455CX +
  26   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
  30   6.0000e-04    FRZ-4 * 3 RANDOM EVENTS +
  50   9.0000e-05    DCF-BDC-STBUS1BX * FRZ-4 * LPR-XHE-FOHOTLGX +
  52   9.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * DCP-BDC-STBUS1AX +
  54   7.0000e-05    FRZ-4 * LPR-XHE-FOHOTLGX * PPS-CCF-FTPORVX +
  73   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
  74   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
  76   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
  77   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
  88   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
  90   2.7000e-05    FRZ-4 * 3 RANDOM EVENTS +
 106   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
 114   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
 115   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
 116   1.2000e-05    FRZ-4 * 3 RANDOM EVENTS +
       ----------
       2.7660e-02
          FREQUENCY = (0.00048) * (0.1) * (2.766e-02) * M = 5.31e-09


                     SRY-FIRE-SEQ3-B =

                     SRY-FIRE-SEQ4-B =

   4   1.0000e+00    FRZ-2 * LPR-XHE-FOHOTLGX +
          FREQUENCY = (0.005) * (0.1) * Q = 2.50e-08

------------------------
   7   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +
  10   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +
  13   1.5000e-04    FRZ-2 * LPR-CCF-FT890ABX +
  14   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +
  18   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +
  23   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +
       ----------
       1.4300e-03
          FREQUENCY = (0.005) * (0.1) * (1.43e-03) * Q = 3.58e-11

------------------------
   1   1.0000e+00    FRZ-4 * LPR-XHE-FOHOTLGX +
          FREQUENCY = (0.00048) * (0.1) * Q = 2.40e-09

------------------------
   5   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +
   8   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +
  11   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +
  17   1.5000e-04    FRZ-4 * LPR-CCF-FT890ABX +
  19   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +
  24   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +
       ----------
       1.4300e-03
          FREQUENCY = (0.00048) * (0.1) * (1.43e-03) * Q = 3.43e-12


                     SRY-FIRE-SEQ5-B =
```

```
  4   6.3000e-04    FRZ-2 * LPI-CCF-FSSI1ABX +
  7   3.0000e-04    FRZ-2 * RMT-CCF-FAMSCALX +
 10   1.5000e-04    FRZ-2 * LPR-CCF-FT862ABX +
 13   1.5000e-04    FRZ-2 * LPR-CCF-FT863ABX +
 15   1.5000e-04    FRZ-2 * LPR-CCF-FT860ABX +
 18   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-2 +
      ----------
      1.4300e-03
        FREQUENCY = (0.005) * (0.1) * (1.43e-03) * Q = 3.58e-11
-------------------------
  3   6.3000e-04    FRZ-4 * LPI-CCF-FSSI1ABX +
  6   3.0000e-04    FRZ-4 * RMT-CCF-FAMSCALX +
  8   1.5000e-04    FRZ-4 * LPR-CCF-FT862ABX +
 12   1.5000e-04    FRZ-4 * LPR-CCF-FT860ABX +
 14   1.5000e-04    FRZ-4 * LPR-CCF-FT863ABX +
 17   5.0000e-05    LPR-CCF-PGSUMPX * FRZ-4 +
      ----------
      1.4300e-03
        FREQUENCY = (0.00048) * (0.1) * (1.43e-03) * Q = 3.43e-12
```

SRY-FIRE-SEQ6-B =

SRY-FIRE-SEQ7-B =