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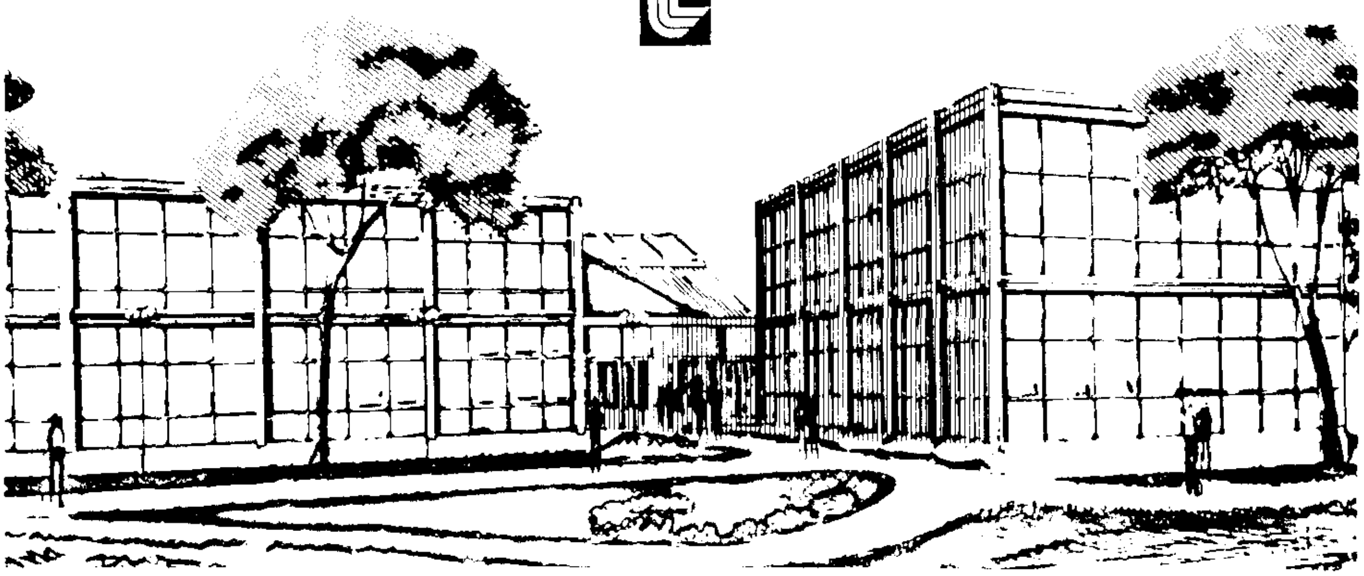

FIRE-PROTECTION STUDY OF THE 2XIIB MIRROR-FUSION FACILITY*

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ABSTRACT

As part of an overall fire safety study for the *2XIIB mirror-fusion* facility at Lawrence Livermore Laboratory, we evaluated the expected performance of its fire protection system. We determined the fire scenarios that would pose a threat to the system and through fault tree analysis made a qualitative and quantitative assessment of the system design taking into account system hardware and maintenance policies. Special emphasis was placed on evaluating the availability of the monitoring circuit of the automatic sprinkler system--a task often excluded in typical availability studies of fire protection systems.

Results of the study indicated an overall system availability of 82%, i.e., there is an 82% probability that the system will work upon demand. The quantitative fault tree analysis revealed that system failure is dominated by the following events: (1) insufficient heat to fuse the sprinkler heads, (2) insufficient smoke to trigger the smoke detectors, and (3) single-point failures in the electrical components of the system circuitry. The primary risks from system failure are loss of life or termination of research or excessive experimental delay; the secondary risks are costly repair and retrofitting of support systems.

INTRODUCTION

We have been using the 2XIIB mirror fusion facility at Lawrence Livermore Laboratory (LLL) to study the fire safety of state of the art fusion energy experiments. In this phase of the study, we examine the facility's fire protection system to assess the adequacy of its performance and diagnose possible shortcomings. In assessing the fire risk associated with the 2XIIB fire protection system,' we considered (1) the magnitude of the facility's exposure to fire if the protection sytem failed, (2) the probability that the system would fail to operate upon demand (system unavailability) (P_f), and (3) the probability that the system would operate but be unsuccessful in extinguishing a fire before major damage occurred ($P^o{}_t$). Item number two is the central issue addressed in this paper.

Through failure modes and effects analysis we examined credible modes of hardware failure and determined their effect on the system. Through qualitative and quantitative fault tree analysis, we assessed system design, system hardware, and maintenance policies. The qualitative analysis required generating system failure modes (minimal cutsets) and identifying single-point failures and common cause events. The quantative analysis entailed collecting and estimating data for component failure, identifying maintenance policies for components, computing system unavailability, calculating the importance of system faults (basic events) and system failure modes that contributed to the occurrence of the top event in the fault tree--failure of the sprinkler heads to activate upon demand.

THE 2XIIB FIRE PROTECTION SYSTEM

The *2XIIB* facility, housed in the main bay of building 435, is protected by a modified preaction system (Fig. 1) with both an automatic and a manual response. The sprinker system is designed to respond automatically to an intense local fire or catastrophic ignition. The manual response is the response of the building occupants and the Laboratory Fire Department. Building occupants respond by using hand-held fire extinguishing equipment; and the Fire Department responds by dispatching fire fighting personnel to the building.

As shown in Fig. 1, the basic elements of the system are the smoke detectors, the sprinkler heads, the zone-indicating and fire-indicating units, and the drypipe hydraulic system. The portion of the piping that extends from the deluge valve to the sprinkler usually contains pressurized air. In the event of a fire, heat fuses the sprinkler heads and the piping depressurizes to atmospheric pressure. A pressure detection switch then energizes relay R1-2, which causes relay contacts R1-2 to close. Smoke from the fire ionizes a smoke detector, causing an overcurrent signal to be sent from the zone-indicating unit to the fire indicating unit. When relay contacts R1-2 and 2K2 close, the solenoid valve becomes energized and the deluge valve opens, permitting water to pass through the sprinkler heads. It is necessary for both a smoke detector and a sprinkler head to activate for automatic application of water on the fire.

The circuitry in the zone-indicating unit and in the fire-indicating unit operates under three modes: normal current, no current, and overcurrent. When the circuitry is operating under no current, the fire station receives a supervisory alarm and initiates repair of the circuitry. When the circuitry is operating under overcurrent, the fire station receives a fire alarm and firemen are dispatched to the location of the fire.

Testing

The 2XIIB fire protection system is tested on a quarterly basis. Testing consists of placing a freon source near the smoke detector. This closes relay contacts 2K2. Opening drain valve M manually, depressurizes the system and causes relay R1-2 to energize and contacts R1-2 to close. At this point, the air pressure light on the display panel should go on. The test is assumed a success if water appears at the open deluge valve. This procedure only tests the piping around the deluge valve. Since piping is assumed to be clear, tests involving the transport of water through the sprinkler system are not made.

Announced and Unannounced Failures

The fault tree analysis of the zone-indicating and fire-indicating units was based on the availability of power and on the status of the detector and response circuit. Eighteen electrical components are associated with these circuits: fuses, rectifiers, relays, switches, wires, etc. An open circuit in any of these results in the system failing to operate upon demand.

Nine of these components are such that when they fail open circuited, they set off a supervisory alarm. Such failures are called announced failures because they are announced at the time of failure. If the supervisory alarm fails, these component failures are not detectable until the system undergoes maintenance or testing. Thus, they are unannounced failures. Open-circuit failures in the remaining nine components are always unannounced because they can only be detected when the system is tested.

FAULT TREE ANALYSIS

For the fault tree analysis, we used a simplified unit model of the 2XIIB fire protection system (Fig. 1) that was scaled down to include a module of four sprinklers and two ionization type detectors*. We constructed two fault trees: one with the top event "failure to operate on demand", and the other with the top event "inadvertent activation of the automatic sprinklers."

Failure to Operate on Demand

Failure of the ZXIIB fire protection system to perform in the event of a fire occurs when

- Two out of two smoke detectors fail to ionize <u>or</u>
- Four out of four sprinkler heads fail to fuse <u>or</u>
- The valving and piping system fails to deliver water to the sprinkler heads <u>or</u>
- The zone-indicating circuitry or fire-indicating circuitry fails to activate the solenoid valve <u>or</u>
- The solenoid actuator fails.

The "failure to operate" fault tree describes the failure causes for sprinkler heads or smoke detectors as (1) primary failures, (2) secondary failures, or (3) performance-related failures. A primary failure is failure from internal causes; secondary failures are failures from external causes, i.e., failure outside the design envelope; and a performance-related failure is failure of the system components to detect or

*This model could later be expanded to a full-scale representation of the ZXIIB fire protection system.

react to the fire given that they are operational. We used these three failure causes to define the failure modes for sprinkler heads, as shown in Table 1.

QUALITATIVE ANALYSIS

With the use of the computer code FTAP[2], we found a total of 713 minimal cutsets (system failure modes) for our unit model. We classified these cutsets according to order, i.e., according to the number of basic events they contained. Specifically, if a minimal cutset contained a single-point failure, it was of order 1; if it contained two event failures, it was of order 2; etc. Of the 713 minimal cutsets found with the computer code, 42 were of order 1, 32 were of order 2, 14 were of order 3, and 625 were of order 4.

Of the 42 single-point failures, 18 involved component failures in the fire-indicating and zone-indicating units; five involved human error, performance-related failures, or secondary failures in the sprinkler heads or the smoke detectors; 1 involved the unavailability of offsite power for more than 24 hours; 1 involved the unavailability of service water; and 17 involved component failures in the piping and valving system.

The minimal cutsets of order 2 through order 4 involved a combination of (1) primary failures in the smoke detectors, (2) primary failures in the sprinkler heads, and (3) failures in the electrical and hydraulic components.

QUANTITATIVE ANALYSIS

Components within the fire protection system were subjected to one of the following three maintenance actions:

- No repair
- Announced failure
- Unannounced failure

An undetected plug in the drypipe system is an example of a no repair case.

To calculate the failure of system components, we had to know the following reliability parameters:

- Failure rate h*, the conditional probability of failure
- Inspection interval Θ (3 months for the 2XIIB fire protection system)
- Repair time T**

We used the computer code IMPORTANCE[3] to calculate (1) system unavailability and (2) the quantitative importance of basic events and minimal cutsets contributing to system failure. Our results showed that the probability of a system failing upon demand, i.e., in the event of a fire, is 0.18 and that 9 basic events contribute to system failure. In Table 2 we list these events, which are ranked according to their relative importance.

System availability is relatively poor. Availability was computed at 82% (1 minus system unavailability). This figure is poor compared to actual performance statistics of the National Fire Protection Association whose 1924-1969 survey yielded a 96% availability for conventional wet pipe systems. The major contributors to system failure are common-cause failures in sprinkler heads and smoke detectors. However, unannounced failures in the electrical components of the zone-indicating and fire-indicating units are also significant contributors.

Sixty-four' percent of the failures contributing to system failure were common-cause failures. Forty percent+ were failures in electrical components, which are always unannounced.

Currently, efforts are being made to improve the availability of the system. Basically, there are two options available to correct the single point failures in the FIU/ZIU units:

- Bypass the units so that the sprinkler system is independent and only the fusing of a sprinkler head is necessary to release water on the fire.
- Redesign the FIU/ZIU units using parallel circuits rather than the present series design, which would supervise all the critical components.

The common cause failures for sprinkler heads and smoke detectors can be partically remedied through care in sitting and care in preventing obstructions.

The probability estimates for sprinkler head and detector failures were assigned on the basis of conservative engineering judgment. By decreasing the testing interval, we can reduce the contribution of these failures to system failure; however, we can also increase the chances for human error and the down time of the system.

* Failure rate data were obtained from the National Fire Protection Association, Factory Mutual Research Corp. IEEE Standard 500, The Reactor Safety Study, and the United Kingdom Atomic Energy Agency.

** Repair time data were obtained from the 2XIIB maintenance crew, the plant engineering personnel at LLL, and the LLL fire department.

\+ The sum of 64 and 40 exceeds unity because the probability of two or more minimal cutsets occuring simultaneously is not negligible.

Inadvertent Activation of the Automatic Sprinklers

A major concern of the personnel conducting the 2XIIB experiment is the accidental release of water on highly sensitive equipment.

The fault tree for "inadvertent release of water", although smaller and more preliminary than the one for "failure to emit water" (which was composed of 26 basic events and generated 42 cutsets of order 2), included basic events such as improper testing and installation of sprinkler heads; breakage of piping caused by machinery and the movement of large pieces of equipnent; and activation of smoke detectors inadvertently set off by cigarette smoke or welding. We could solve the problem created by the smoke detectors by increasing their detection thresholds. However, this solution would cause an undesirable delay in warning time.

The calculated probability of an inadvertent release of water occuring was 5.7 x 10^{-8}/day, or 2.0 x 10^{-5}/year. The calculated probability for a breach or waterflow in the sprinkler system was approximately 10^{-4}/day.

CONCLUSIONS

Based on the results of the quantitative analysis, we calculated a system unavailability of 1.8 x 10^{-1}, or 18/100 per demand, for system failure. This results in a system availability of 82%. Using the computer code IMPORTANCE[3], we ranked the events of the fault tree according to their individual contributions to the undesired event. The most important contributors to system failure were insufficient smoke to smoke detectors and obstructed sprinkler heads. Single-point failures associated with the fire-indicating and zone-indicating circuits were also important.

Other single-point failures contributing to system failure were associated with the sprinkler system and the piping network. They primarily involved the deluge valve and the process air. For example, in the piping network, we found debris from scale, and an open master drain valve as causes for failure. Thus, the availability of the piping network depends on the frequency and length of repair and service intervals.

The low probability of an inadvertent release of water correlates with the system's 82% availability figure. Designing the fire protection system against inadvertent release of water makes it more difficult for the system to activate when an actual fire occurs.

We believe that the results of the 2XIIB fire protection study will help determine the adequacy of fire protection systems in other fusion facilities. The combined results of future studies will help establish design criteria for fire-safe fusion facilities.

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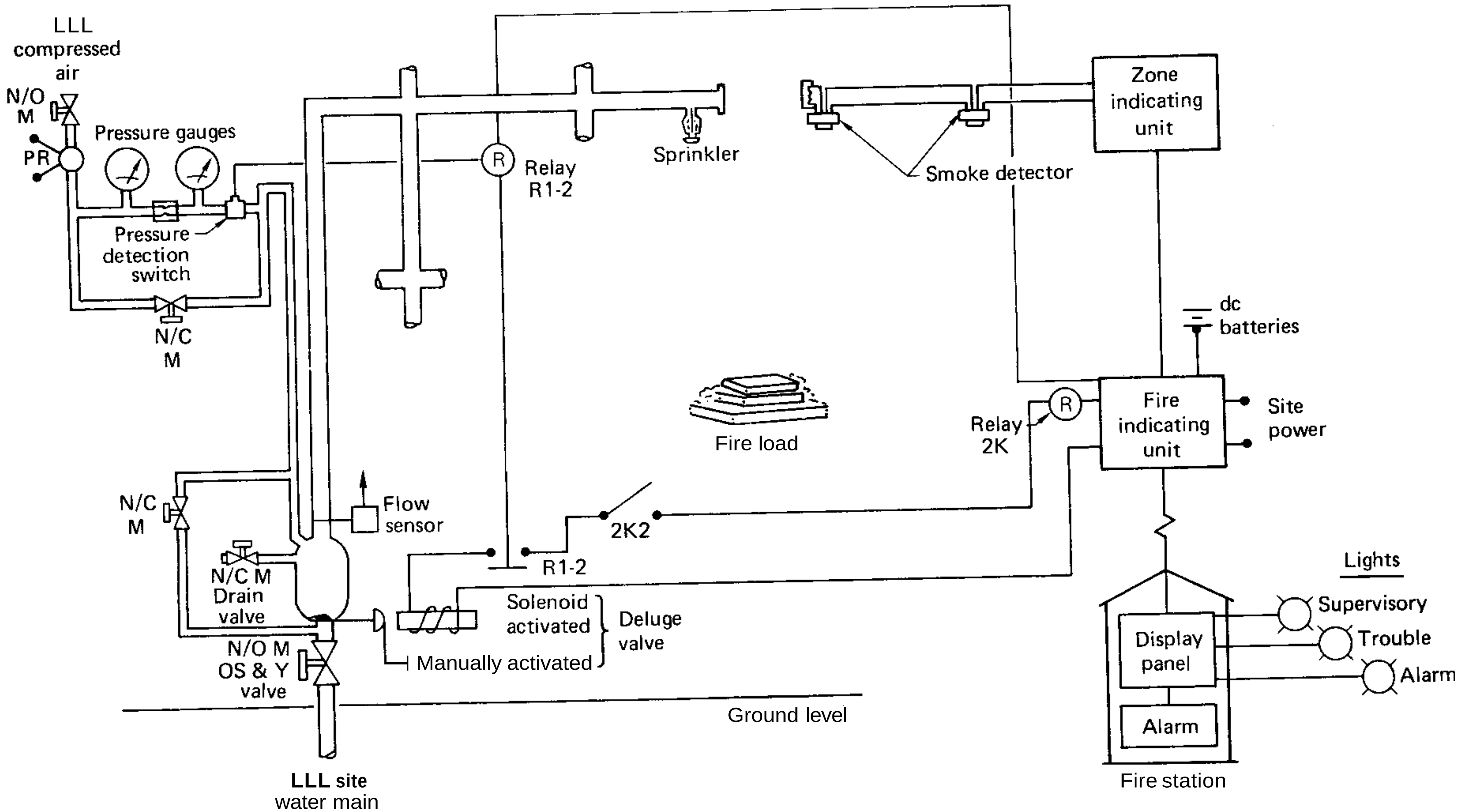

Fig. 1 Functional Block Diagram of the 2XIIB Fire Protection System

Table 1. Major failure modes for sprinkler heads.

Failure mode	Failure cause
1. Sprinkler head fails to fuse open	Primary failure
2. Sprinkler head is corroded	Secondary failure
3. Heat is obstructed from sprinkler	Secondary failure
4. Sprinkler head is installed in the wrong position	Secondary failure
5. There is not sufficient heat to fuse sprinkler head	Performance-related failure

Table 2. Basic events contributing to system failure.

Basic event	Rank	IMPORTANCE[b]
Smoke is inadequate to ionize both detectors	1	.27
Heat is inadequate to fuse all four sprinkler heads	1	.27
Rectifier CR5 fails open circuited[a]	2	.12
Rectifier CR1 fails open circuited[a]	2	.12
Rectifier CR2 fails open circuited[a]	2	.12
Heat is obstructed from all four sprinkler heads	3	.05
All four sprinkler heads are installed in the wrong position	3	.05
Fuse F3 fails open circuited[a]	4	.03
Switch S4-3 fails open circuited[a]	5	.01

[a] Failures within the zone-indicating unit or the fire-indicating unit are always unannounced.

[b] Defined as the probability that the basic event occurs divided by the probability of the top event.

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