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TITLE: LIMITED-SCOPE PROBABILISTIC SAFETY ANALYSIS FOR THE LOS ALAMOS MESON PHYSICS FACILITY (LAMPF)

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AUTHOR(S): Mohsen Sharirli
John L. Rand
M. Kent Sasser
Floyd R. Gallegos

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Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

LIMITED-SCOPE PROBABILISTIC SAFETY ANALYSIS FOR THE LOS ALAMOS MESON PHYSICS FACILITY (LAMPF)

Mohsen Sharirli, John L. Rand, M. Kent Sasser, and Floyd R. Gallegos
Los Alamos National Laboratory
Los Alamos, NM 87545

ABSTRACT

The reliability of instrumentation and safety systems is a major issue in the operation of accelerator facilities. A probabilistic safety analysis was performed for the key safety and instrumentation systems at the Los Alamos Meson Physics Facility (LAMPF). In Phase I of this unique study, the Personnel Safety System (PSS) and the Current Limiters (XLs) were analyzed through the use of the fault tree analyses, failure modes and effects analysis, and criticality analysis. Phase II of the program was done to update and reevaluate the safety systems after the Phase I recommendations were implemented. This paper provides a brief review of the studies involved in Phases I and II of the program.

I. INTRODUCTION

In 1990, the Engineering and Safety Analysis Group (N-6) with cooperation of Medium Energy Physics Division (MP) performed a study of Personnel Safety System (PSS) and Current Limiters (XLs) for the Los Alamos Meson Physics Facility (LAMPF). This study has been part of the radiation safety and safety evaluation assessment for the Los Alamos Neutron Scattering Center/Weapons Neutron Research (LANSCE/WNR) facility. The study, the first of its kind for an accelerator facility, involved using tools such as fault tree analysis and failure modes and effects analysis. These types of analyses have been used extensively by defense programs, the commercial nuclear industry, space programs, and the chemical industry. This study selected two systems—the PSS and the XLs—for this pilot program. These two systems are both important to safety and possess diverse characteristics (i.e., PSS is a multifunction, large, expanded system that extends almost one-half mile, whereas XL is a small moveable unit), which resulted in choosing them for this study.

Phase I involved assessing the feasibility of applying probabilistic risk assessment (PRA) techniques to LAMPF. This assessment was accomplished by performing a PRA of the PSS, namely, the transport beam plugs, associated interlocks and controls, and XLs. Several important findings and recommendations resulted from the PRA analysis in Phase I. Phase I was completed in October 1990.

The recommendations made for the operation and design modifications for the XLs and for PSS in Phase I of the study were incorporated and implemented. When we obtained information about the reliability of PSS, we verified whether the modifications resulted in any unexpected increases in unreliability and instead resulted in gains in the reliability margins for the system. Phase II reevaluated the new design, with modifications, of the PSS and XL systems. In addition, the Phase I report was updated based on comments and suggestions of accelerator facility personnel. The reevaluation phase was completed in September 1992.

Phases I and II, and the resulting insights and recommendations, are discussed in this paper.

II. SYSTEM DESCRIPTION

Generally, three systems—the PSS, run permit (RP), and fast protect (FP)—can turn the beam off automatically if excess beam spill, fault equipment, or open interlocks are detected. There is also a manual mode beam gate inhibit, which gives the operator quick manual input to stop H^- production. The manual mode also may be activated by the beam-line computer software. Figure 1 is a simplified drawing of beam-stop locations at LANSCE.

A. Description, design, and operation of the PSS

The PSS transport beam plugs and associated interlocks and controls include pieces of equipment from many detection areas and controls to the various beam plugs (the six major beam plugs are 01BL1, TABL1, TBBL1, TCBL1, LDBL01, and LDBL02) used in the analysis. The PSS includes interlocks on exclusion areas, beam plugs, and instrumentation designed to protect personnel from excess radiation. A fault of the PSS will interrupt all three beams in the LAMPF accelerator and then insert beam plugs to ensure that no beam can reach the area where the fault occurred.

The RP and FP systems are designed to protect beam-line equipment from damage resulting from errant beams and to limit beam spills to levels below the threshold of the PSS instrumentation. Failure of the RP and FP systems will not compromise the protection afforded by the PSS. The PSS system includes the beam plugs, a large number of relays and contact pairs, various switches and keys, interlocks, and controls that are involved in the system operation. These interactive components are distributed in various areas that could extend out to about one-half mile at some points. Figure 2 is a representation of the LANSCE/WNR PSS safe-string logic. The nodes in Fig. 2 indicate functions and systems for operation of the system.

B. Description, design, and operation of the XLs

The XLs provide a reliable means to monitor various areas and detect the average current outside the threshold limit. The XL system functions as one of the monitoring sources that provides input

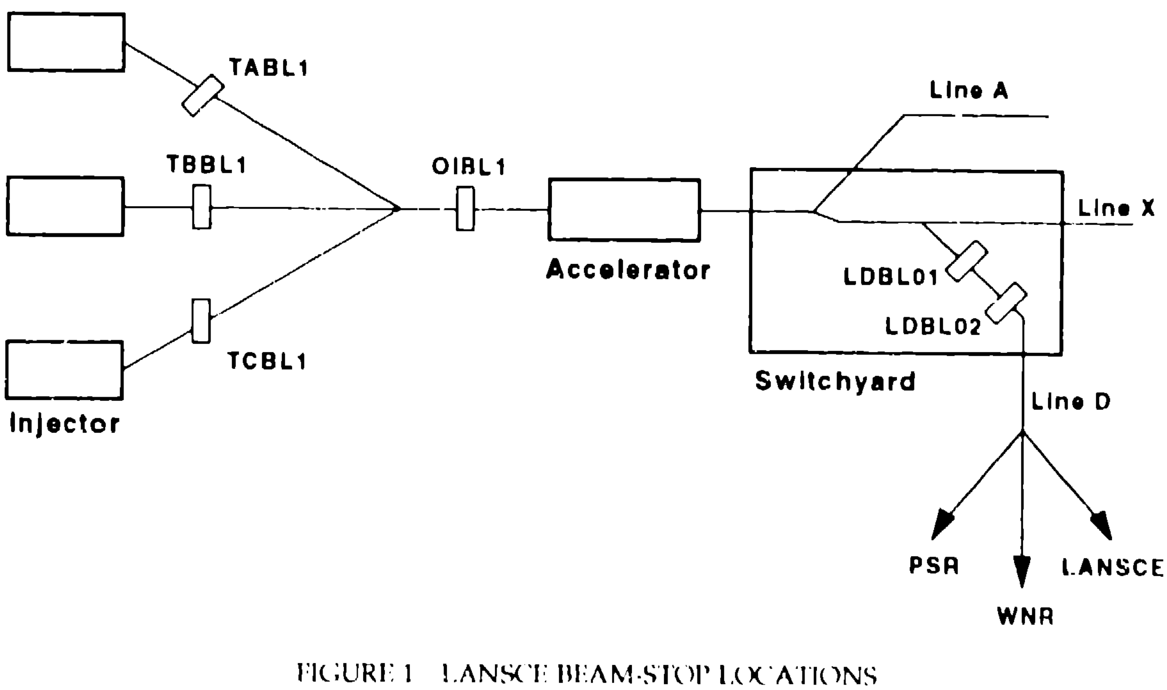

FIGURE 1 LANSCE BEAM-STOP LOCATIONS

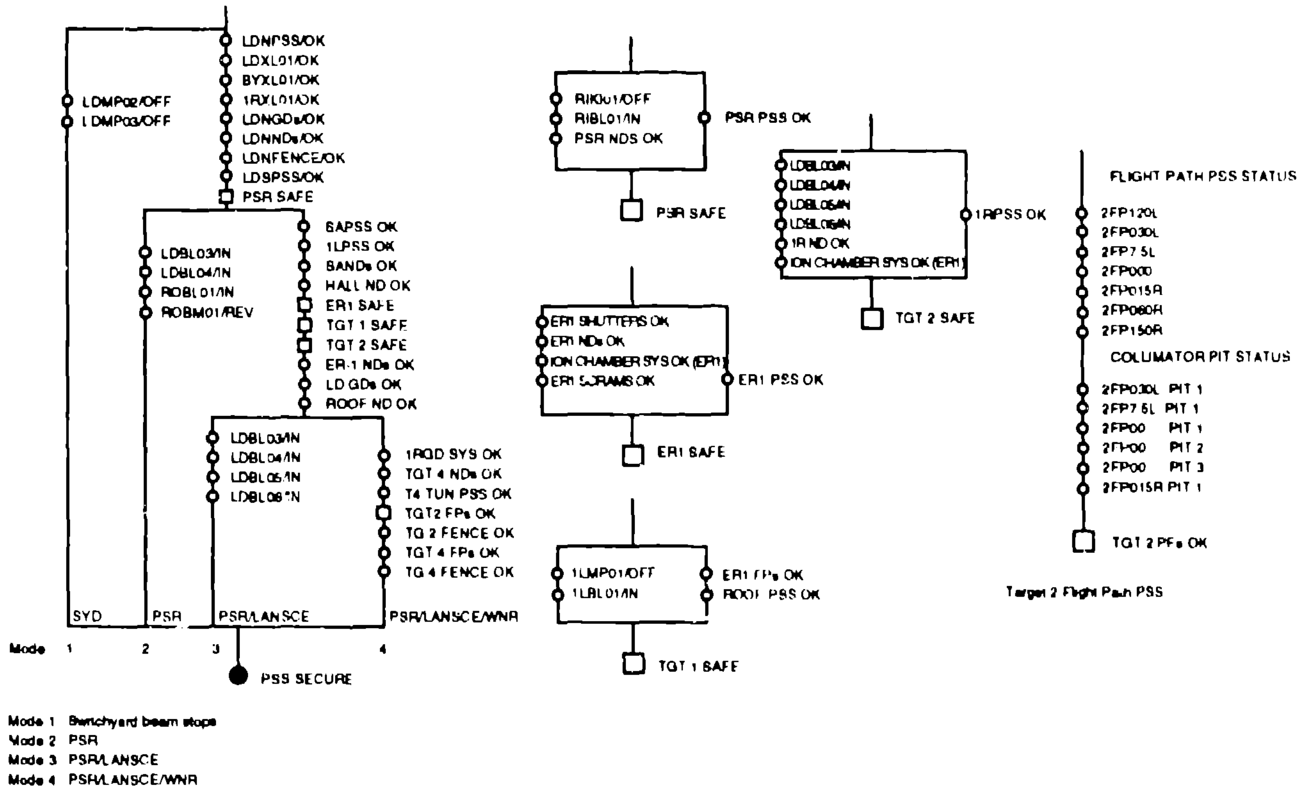

FIGURE 2 LANSCE/WNR PSS SAFETY STRING LOGIC

to the PSS. The system is set at 3 μA to shut the beam off. The XL is referred to as a fail-safe system and is designed to shut the beam off upon failure of equipment. This information is then transmitted to the PSS, which in turn will respond as needed. The XL is a small movable piece of equipment 18 in. high x 17.5 in. wide x 14 in. along the beam axis, and has a self-contained power supply and electronic circuitry. The fail-safe features of the XL include (1) self-checking pulses and cancellation circuitry, (2) power monitoring in the fault circuitry, (3) redundancy (two independent fault channels) when self-checking is not effective, and (4) printed circuit boards inter-locked and keyed for proper insertion.

III. ANALYSIS OF PSS AND XLS

An analysis of the PSS and XLs was performed initially using failure modes and effects and criticality tools to examine the system's components and potential equipment failures. The PSS and XLs were then analyzed through the use of fault tree analysis. The analysis of the PSS and XLs required traditional safety study methodologies, which have been developed and proved in the other industries previously mentioned:

- success criteria parameters
- human reliability analysis
- human reliability quantification
- common-cause failure analysis
- fault tree development and analysis
- modeling assumptions and definitions
- data collection and analysis
- quantitative and qualitative analysis
- recovery analysis
- post analysis calculations

The human reliability analysis was performed using a standard human reliability analysis procedure, as discussed in Ref. 1. The component failure data were gathered from a number of sources and evaluated as to their applicability to components in the PSS and XL fault trees. The information for components was obtained from Refs. 2, 3, 4, and 5. For the fault tree analysis, the Set Equations Transformation Systems (SETS) code[6] was used. To perform additional quantitative analysis and post-analysis calculations, the Set Evaluation Program (SEP) code[7] was used.

IV. PHASE I RESULTS AND RECOMMENDATIONS

In addition to analyzing the PSS and XL systems, the analysis provided for unreliability of these systems. (Unreliability is the system failure probability per event occurrence; that is, given a failure such as a beam spill, the unreliability factor would be the conditional failure probability of the PSS to detect, respond, and operate as required.) Also, uncertainty and sensitivity analyses were performed by identifying the component's contributions to the systems' unreliability.

The analysis estimated that the PSS and XLs have unreliabilities of 9.2E-4 and 3.7E-3, respectively. The uncertainty results indicated an error factor of 2.3 and 2.2 (95th/50th percentiles) for the PSS and XLs, respectively. The analysis also provided tens of thousands of cut sets, which are the combinations of events that, should they occur, would fail the system.

For PSS, the results estimated the mean and the standard deviation of (1.2E-3, 6.0E-4), (1.2E-3, 6.0E-4), (4.9E-8, 4.9E-8) for the total, singles, and others, respectively. For the total, the values of (4.9E-4, 1.0E-3, 2.3E-3) for the 5th, 50th, and 95th percentile were calculated.

For the XLs, the results estimated the mean and the standard deviation of (5.1E-3, 2.7E-3), (4.9E-3, 2.7E-3), (1.8E-4, 1.3E-4), and (1.1E-8, 7.9E-9) for the total, singles, doubles, and other, respectively. For the total, the values of (2.5E-3, 4.5E-3, 9.8E-3) for the 5th, 50th, and 95th percentile were calculated.

The recommendations involved several modifications in hardware as well as changes in testing and maintenance and procedures based in the human reliability analysis, as follows.

1. For the XLs, add a capability to perform weekly tests, similar to the PSS operations.

2. For the PSS, remove or eliminate all areas (such as terminals and redundant cabinets) in which there is potential for human error.

3. For both PSS and XLs, implement proposed recommendations regarding procedures and operations to reduce human errors.

4. Evaluate ways, such as adding auxiliary line(s) with relay(s), to provide independent paths for portions of the PSS.

5. Implement locking and tagging procedures to encompass maintenance, modifications, or other activities on the PSS during an operating period.

6. Implement independent verification procedures for independent checks of critical activities of safety significant equipment, and implement a second sign-off by independent verifier.

V. PHASE II REEVALUATION

An update and reevaluation was performed for Phase II. This involved collecting comments, reviewing and analyzing them, and incorporating them into the report, as well as updating the Phase I report (Task 4). Task 5 involved assessment and reevaluation of the analysis in light of modifications taking place at the facility. These two tasks were completed in September 1992.

Almost all modifications performed impacted the PSS. Therefore, the analysis of XLs in Phase II remained unchanged, whereas the revaluation of PSS involved a complete reanalysis of this system.

VI. CONCLUSIONS AND RECOMMENDATIONS

The reevaluation study provided thousands of cut sets for PSS. It also showed a PSS unreliability of 3.1E-4. The uncertainty results indicated an error factor of 2.1 (95th percentile/50th percentile). Also, the results showed the mean and the standard deviation of (3.7E-4, 1.8E-4), (3.7E-4, 1.8E-4), (4.9E-9, 4.1E-9) for the total, singles, and others, respectively. For the total, the values of (1.6E-4, 3.4E-4, 6.8E-4) for the 5th, 50th, and 95th percentile were calculated. In addition to the information gained in the analysis, some of the more significant insights have been discussed here.

The probability for cut sets started at very low values. At a cut off of 1.0E-12, the analysis of Phase I configuration resulted in 797 cut sets and system unreliability of 9.2E-4. The Phase II reevaluation yielded 314 cut sets and a system unreliability of 3.1E-4. This showed a 67% reduction in system unreliability and over a 60% reduction in total cut sets with probabilities higher than 1.0E-12 and orders of 3. There were also various other significant items including reduction in hardware and potential human error.

The recommendations include the following:

1. Remove any remaining potential areas for human error. Most of the items in question are locked and logged in the appropriate cabinets. Plans are under way to implement future improvements.

2. There have been significant modifications to the procedures since the initial analysis; however, continued updating of the procedures is recommended. Plans continue to be implemented for future improvements.

3. Other improvements in the areas of independent checks and incorporation of a second sign-off block are recommended.

Finally, the analysis provided important information for the operators, designers, and the staff at LAMPF. Plans are to use similar studies for other areas of the facility. The analysis also provided information to be shared with others in the accelerator community. A favorable review of PRA applications to accelerators was received at an accelerator safety workshop hosted by LAMPF and attended by representatives from all Department of Energy accelerator facilities.

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