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PRECURSORS TO POTENTIAL SEVERE CORE DAMAGE ACCIDENTS: 1969–1979 A STATUS REPORT

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REPORT SUMMARY

The Accident Sequence Precursor study involves the review of Licensee Event Reports of operational events that have occurred at light-water power reactors to identify and categorize precursors to potentially significant accident sequences. Accident sequences considered in the study are those that could lead to severe core damage. Accident sequence precursors of interest are events that are important elements in a chain of events (an accident sequence) possibly leading to core damage. Such precursors might be infrequent initiating events or equipment failures that, when coupled with one or more postulated events, could result in a plant condition leading to severe core damage.

A nuclear plant has safety system equipment for mitigating accidents or off-normal initiating events that may occur during the course of plant operation. These safety systems are built to high quality and are redundant; nonetheless, they have a definite probability of failing or being in a failed state when required to operate. This report uses LERs and other plant data to calculate the unavailability of plant safety systems. It then uses these calculated safety system unavailabilities and the expected average frequency of initiating events (loss of feedwater, loss of offsite power, loss-of-coolant accidents, and steam line breaks, also determined when possible from the precursors) to evaluate the end results of safety system unavailability for two situations:

1. Safety system failures without initiating events. Given an LER-reported failure of a safety system or partial failures in several systems, the report uses expected initiating event occurrence rates to determine the number of initiating events that will challenge the failed and backup safety systems during the period the safety system is failed. It multiplies the challenges by system failure probabilities, using event trees to evaluate the likelihood of the overall event sequence occurring.

2. Initiating event occurrences. Although standby safety systems are ideally always available, there is a statistical probability that these systems will fail when called on to mitigate expected accident or transient initiating events. Therefore, the report calculates the likelihood of severe core damage occurrence for each LER-reported initiating event based on expected response (failure probabilities) of the safety systems. Failed or degraded safety systems existing at the time of the initiating event are accounted for in the calculations.

The study effort has been divided into several tasks, which are described in detail in later sections of this report. These tasks include (1) selection of LERs for detailed review as precursors; (2) in-depth review of those LERs; (3) identification, description, and categorization of events considered to be precursors; (4) selection of precursors considered significant; and (5) subsequent analysis of the precursors to determine if any trends or unique relationships exist among them.

For this study, LER events were selected as precursors if they met one of the following requirements:

1. The event involved the failure of at least one function required to mitigate an initiating event of interest.

2. The event involved the degradation of more than one function required to mitigate an initiating event of interest.

3. The event involved an unusual actual initiating event (e.g., a total loss of offsite power, a stuck-open primary relief valve, or another infrequent event).

Approximately 19,400 LERs concerning events that occurred during 1969–1979 were screened for accident sequence precursors according to the above requirements. Of these, over 500 LERs (~3%) were selected for detailed review.

All LERs selected for detailed review were subjected to an in-depth evaluation, which included

1. a review of the accident sequence (if there was one) as described in the LER,

2. a review of the design of systems in the reactor plant reporting the LER to determine the impact of the failure on the operation of these systems, and

3. a review of the plant accident analyses to determine the extent to which affected systems would be required to function for different off-normal and accident conditions.

As a result of this detailed review, 169 events were selected as accident sequence precursors. For each of these events, four items were prepared: a sheet describing the event, a categorization sheet including event- and reactor-specific information used in subsequent analyses, and two event trees. The first event tree describes the actual occurrence as reported in the LER and identifies the potential for severe core damage stemming from the actual event. The second event tree describes a postulated sequence of events that could have been affected by the actual reported failures. A set of these four items for each of the 169 events is included in Appendix B.

The failure information contained in the precursors was used to estimate initiating event frequencies and function failure-on-demand probabilities. This information was used, in conjunction with the precursor event trees, to determine a measure of the probability of severe core damage associated with each event sequence. This probability is an estimate of the chance of severe core damage given the precursor event occurred in the manner it did. These probability measures were then used to rank the precursors. Fifty-two precursors with probability measures of $\geq 10^{-3}$ were selected as significant.

The probabilities of severe core damage associated with the precursors were also used to estimate the frequency of severe core damage per reactor year for the years 1969–1979. This point estimate is between 1.7 $\times 10^{-3}$ and 4.5 $\times 10^{-3}$ per reactor year and includes contributions from three major events: (1) the loss of feedwater and stuck-open relief valve at Three Mile Island Unit 2 (which actually resulted in severe core damage), (2) the loss of nonnuclear instrumentation at Rancho Seco, and (3) the fire in the cable spreading room at Browns Ferry 1.

These numbers are compared with other estimates from PRAs and from the TMI-2 event alone in Fig. 1.

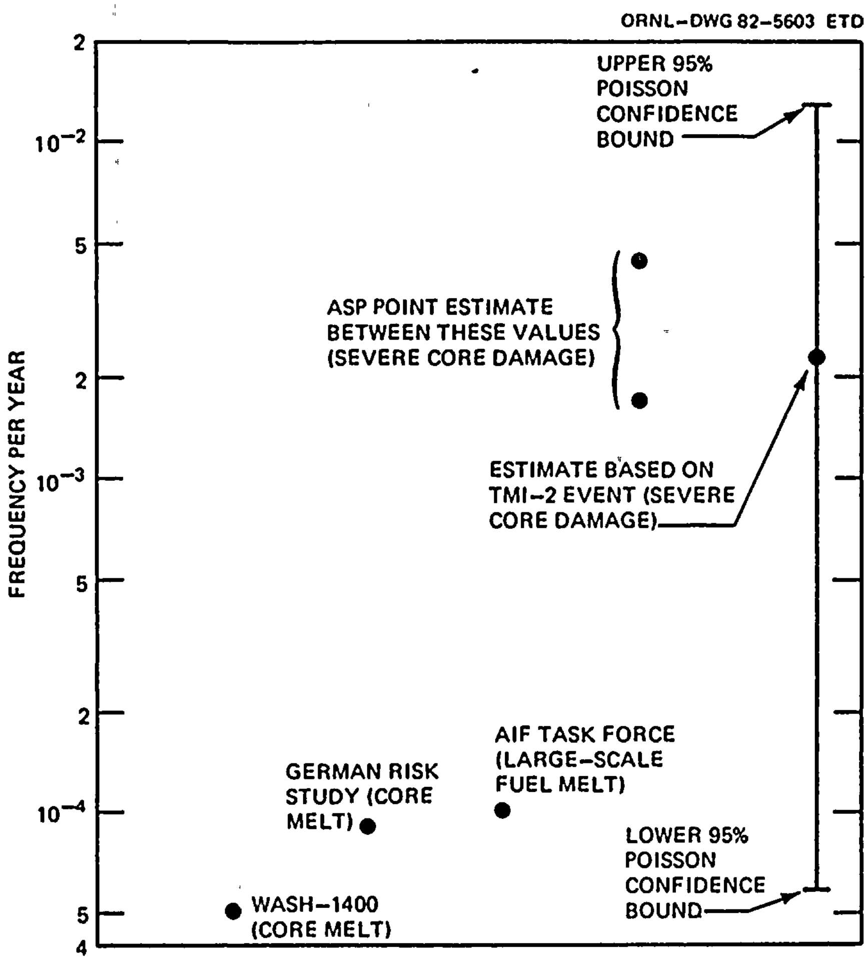

Fig. 1. Comparison of ASP results with other core damage estimates.

Subsequent analyses of the information included in the selected precursors resulted in the following additional conclusions:

1. Many of the initiating event frequencies and function failure-on-demand probabilities developed from operational event information agree reasonably well (within a factor of 10) with the *Reactor Safety Study*[1] median results.
2. A variation in the rate of occurrence of significant precursors per plant as a function of plant age cannot be justified.
3. Differences do not appear to exist in the number of significant precursors observed between plant types and among reactor vendors, architect-engineers, and plant power ratings.
4. Approximately 38% of all significant precursors involved human error.

These analyses did not involve extreme statistical sophistication but were first attempts to determine if trends were discernible in the selected events. Changes made in reactor plant operation after the TMI-2

accident (particularly the potential use of high-pressure injection following auxiliary feedwater system failure and the ability to provide flow from at least one auxiliary feedwater pump during a loss of ac power in PWRs) are expected to reduce this estimate considerably in later years.

For reference, highlights of this study are summarized in Table 1.

Table 1. Accident Sequence Precursor study highlights

Period covered	1969–1979
Total number of LERs searched	19,400
Number selected for detailed review	529
Number selected as precursors	169
Number of significant events	52

A point estimate of the frequency of severe core damage calculated from precursor information for the years 1969–1979 lies between 1.7×10^{-3} and 4.5×10^{-3} per reactor year.

Reasonable agreement exists between ASP and *Reactor Safety Study* initiating event frequencies and function failure probabilities.

No variation with plant age can be demonstrated in the number of significant events.

No apparent differences exist between plant types and among vendors, architect-engineers, and plant power ratings.

Reference

1. U.S. Nuclear Regulatory Commission, *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, WASH-1400 (NUREG-75/014) (October 1975).

PRECURSORS TO POTENTIAL SEVERE CORE DAMAGE ACCIDENTS: 1969–1979 A STATUS REPORT

J. W. Minarick* C. A. Kukielka*

ABSTRACT

Descriptions of 169 operational events reported as Licensee Event Reports, which occurred at commercial light-water reactors during 1969–1979 and which are considered to be precursors to potential severe core damage, are presented, along with associated event trees and categorizations and subsequent analyses. The report summarizes work in (1) the development of methods used to screen ~19,400 LER abstracts for potential precursors, (2) the initial screening of those abstracts to determine which should be reviewed in detail, (3) the detailed review of those selected LERs that yielded the 169 events, (4) the categorization of the 169 events, (5) the calculation of function failure estimates based on precursor data, (6) the use of probability of severe core damage estimates to rank precursor events and estimate the frequency of severe core damage, (7) the identification of 52 events considered significant, (8) trends analyses of those significant events, and (9) the identification of the other events of interest that occurred within 1 month of significant events.

1. INTRODUCTION

The Accident Sequence Precursor study involves the review of Licensee Event Reports of operational events that have occurred at light-water power reactors between 1969 and 1981 to identify and categorize precursors to potential severe core damage accident sequences. This progress report details this effort for 1969–1979 LERs. Although Licensee Event Reports were not required until mid-1975, event reports comparable to LERs existed before the inception of the LER system and are considered to be LERs for the purpose of this study. [The requirements of Licensee Event Reports are described in Regulatory Guide 1.16 (Ref. 1).] Work on the ASP study began at the Nuclear Safety Information Center on June 15, 1979, in response to FY-1979 Nuclear Regulatory Research Order 60-79-185, "Accident Sequence Precursor Study" dated June 7, 1979, and subsequent orders.

The program was initiated, in part, because of conclusions contained in the *Risk Assessment Review Group Report*.[2] This report states "that unidentified event sequences significant to risk might contribute . . . a

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small increment . . . [to the overall risk]." The report recommends: "It is important, in our view, that potentially significant (accident) sequences, and precursors, as they occur, be subjected to the kind of analysis contained in WASH-1400 [Ref. 3]. . . ."

Accident sequences considered in the study are those that could lead to severe core damage. Accident sequence precursors of interest are events that are important elements in a chain of events (an accident sequence) possibly leading to core damage. Such precursors could be infrequent initiating events or equipment failures that when coupled with one or more postulated events, could result in a plant condition leading to severe core damage.

Note that the results achieved in this report have been obtained based on events reported in LERs and subsequently selected as precursors. Because of the use of LERs, biases may have been introduced as a result of differences in plant technical specifications and approaches to LER reporting and of changes in LER reporting requirements over the period of the study. These considerations may result in the failure to include certain events that under different circumstances would have been selected for inclusion. However, the events selected were more serious than most, and it is expected that most of these would have been reported independently of small differences in reporting requirements.

The ASP study effort has been divided into the following tasks:

1. selection of LERs deserving a detailed review as precursors;
2. detailed review of selected LERs;
3. identification, description, and categorization of events considered accident sequence precursors;
4. selection of precursors that are considered significant; and
5. analysis of precursors to determine if any trends or unique relationships exist.

These tasks are described in detail in the following sections.

References

1. U.S. Nuclear Regulatory Commission, *Regulatory Guide 1.16, Reporting of Operating Information, Appendix A: Technical Specifications*, Rev. 4 (August 1975).

2. U.S. Nuclear Regulatory Commission, *Risk Assessment Review Group Report*, p. 15, NUREG/CR-0400 (September 1978).

3. U.S. Nuclear Regulatory Commission, *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, WASH-1400 (NUREG-75/014) (October 1975).

FOREWORD

This report presents the initial results of a program that was begun as a result of one of the Lewis Committee recommendations following their review of WASH-1400, the *Reactor Safety Study*. One of the committee's review findings was that more use should be made of operational data to assess the risk from nuclear power plants. The Precursor Program, performed at Oak Ridge National Laboratory and administered by the Nuclear Regulatory Commission, responds to this Lewis committee finding. The Precursor Program uses Licensee Event Reports to evaluate potential nuclear plant accident precursors occurring at operating reactors. These individual plant precursors are then summarized to evaluate the risk (for a particular time period) from all operating nuclear power plants. This report, covering 1969–1979 LERs, is being released as a progress report with the expectation that some conclusions may need to be changed as the report undergoes continuing peer review and public comment. The next report (using 1980–1981 LER data) should reflect the risk from nuclear plants since the TMI-2 accident and may show what effects new procedures and equipment modifications (lessons learned) have had.

In addition to the documentation of 169 identified precursors and preliminary trends analyses, the report estimates the frequency of severe core damage based on the precursor information. It is a difficult problem to derive a credible probability for severe core damage using limited operational experience data from plants that have many significant physical and operational differences among them. The authors of this report partially account for plant differences by using generalized (functional) event trees for individual precursor evaluation, which in their quantification are then specialized, as much as possible, to the particular plant. Nonetheless, simplified methods are used to determine and quantify severe core damage precursors. Several aspects of this report are expected to affect the calculated results, either conservatively or nonconservatively. The first two of the following items are expected to introduce a conservative and nonconservative bias, respectively. The remaining items may introduce either conservative or nonconservative biases.

- The probability of subsequent core damage given the precursor may be conservative in some cases.
- The LER screening process may have overlooked precursors that should have been included.
- The accuracy and completeness of the LERs in reflecting pertinent operational failure or initiating events is somewhat questionable.
- The event trees used for most precursors are generic and may not adequately reflect differences among plants.
- Average or generic data are combined with plant-specific operational occurrences in calculating the probability of subsequent severe core damage.
- The repair (recovery) credit for system failure involves engineering judgment.
- The method used to calculate the frequency of severe core damage is subject to various interpretations because of the combined use of event

statistics and generic initiating event and function failure probabilities.

The use of LERs to attempt to extract severe core damage probabilities, on a scale and to the detail such as done in this report, is unique. The full meaning and limitations of the severe core damage calculations made in this report are not clear. It is felt, however, that the report provides valuable information that can help validate or supplement probabilistic risk assessments performed on nuclear power plants. Much of the basic data and information needed for additional calculations or inferences of reactor risk by the reader is included in the report. As mentioned, this report will be followed by other reports that will evaluate LERs in the 1980-1981 time period and also will provide further analysis, refinement, and practical use of the basic data contained within this report.

Reader comments and suggestions are earnestly solicited and should be sent to the Chief, Reactor Risk Branch, Division of Risk Analysis, at the address below.

R. M. Bernero, Director
Division of Risk Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

PREFACE

The work reported here was undertaken by the Nuclear Operations Analysis Center at Oak Ridge National Laboratory on behalf of the Division of Risk Analysis of the Nuclear Regulatory Commission. The FY-1982 NRC technical monitor, F. M. Manning, succeeded M. A. Taylor, who was technical monitor until his reassignment in November 1981. The work on accident sequence precursors was initiated early in 1979 with R. L. Scott as project manager, assisted by the authors of this report. However, when Scott was reassigned in July 1980, J. W. Minarick became acting manager and has retained that role since. Both Minarick and C. A. Kulkielka are Science Applications, Inc., employees and performed their work under subcontract to NOAC. Most of the work was performed at NOAC offices because of the availability of relevent documents and technical support. The training and background of these authors well qualified them for the task. Minarick, an electrical engineer, has had 12 years of reactor systems experience, including 5 years on Admiral H. G. Rickover's staff and 3.5 years with Babcock & Wilcox Company. Kulkielka, who received his M.S. degree in nuclear engineering in 1979, had 2 years' prior experience with the U.S. Army nuclear program before joining SAI in 1979.

This status report covers the first 2.5 years of effort. The work involved (1) development of selection criteria for the identification of those reactor events that are precursors of potential severe core damage, (2) application of these criteria against all the licensee event reports that have been received since 1969, and (3) detailed analyses of the selected events. This report covers the work completed for LERs submitted during the 11-year period from 1969 to 1979. Although the NRC has previously reviewed the selection criteria and the events selected, it has not been directly involved in the application of these criteria against the existing LERs. This task has been performed entirely by the NOAC staff, using its best judgment in doing so. While this judgment reflects many years of experience in reactor design, reactor operations, and systems evaluations, the process is subjective, and not all specialists will necessarily agree with every event selected and/or omitted.

This report deals only with historical data and, at this point, with minimal statistical interpretation. The TMI-2 accident is responsible for about half the core damage frequency value estimated herein. Yet, could one say — given the conditions of early 1979 — that the frequency of a TMI-2-type accident at that time was once every 4 years or once every 100 years? Furthermore, the same selection criteria that were used in this study would also have been applicable had the top event been severe fuel cladding failure, severe core damage, or core meltdown. In any event, the many changes that have occurred in nuclear plant design and operation since 1979 are expected to substantially reduce the future probability of all such events.

Continuing work on this program is expected to include:

- an assessment of the uncertainty in the core damage probability calculations (a simplified approach, based on the fact that TMI-2 has been the only true core damage statistic, indicates the report estimate could be too low by a factor of 2 to 3 or too large by one or two orders of magnitude) and

- a calculation of the probability of severe core damage accidents based on the ~7500 LERs submitted in 1980 and 1981.

Inevitably, the results of this report will be compared with the data in the *Reactor Safety Study* (WASH-1400) and other probabilistic risk assessment studies. Although the casual reader may interpret the Accident Sequence Precursor study results as incompatible with other core damage estimates, it is quite likely that because of the statistical uncertainty, no significant difference exists. That, of course, remains to be demonstrated.

In conclusion, I direct your attention to the various trends analyses included in this report. Although the statistical precision is not great, the trends are of considerable interest. In any event, the results presented here indicate how very important it is that the operating experience be analyzed for trends that a more casual surveillance of such experience might not reveal.

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