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MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER NO. 117
"PROBABILITY OF LARGE LOCA INDUCED BY EARTHQUAKES"

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## Introduction

The Code of Federal Regulations requires that structures, systems, and components important to the safety of nuclear power plants in the United States be designed to withstand appropriate combinations of effects of natural phenomena coupled with the effects of normal and accident conditions. Designing to withstand the combined effects of an earthquake and a large loss-of-coolant accident (LOCA) is one such load combination requirement that has been mandated for more than 10 years in the design of commercial nuclear power plants. The combination of the most severe LOCA load with safe shutdown earthquake (SSE) loads was not very controversial until about 5 years ago when the postulated LOCA and SSE loads were both increased significantly to account for such phenomena as asymmetric blowdown in pressurized water reactors (PWR) and newly-understood seismic hazard probabilities. There are many operating plants which were not designed for this combination. The question has been raised at the Commission level regarding the basis for their continued operation.

This RIL describes work performed for the U.S. Nuclear Regulatory Commission (NRC) by the Load Combinations Program at the Lawrence Livermore National Laboratory (LLNL) since March 1979 and reported in reference 1. It represents a milestone effort to develop a technical basis for reassessing the requirement that loads resulting from an earthquake and a large LOCA be combined in the design of nuclear power plants. A systematic probabilistic approach is used to treat the random nature of earthquake and transient loading in order to estimate the probability of large LOCAs that are directly and indirectly induced by earthquakes. A large LOCA is defined in this RIL as a double-ended guillotine break of the primary reactor coolant loop piping (the hot leg, cold leg, and crossover) of a PWR. Unit 1 of the Zion Nuclear Power Plant, a four-loop PWR-1, is used for this study.

Primary system piping typically has outside diameters of 30 inches or more, and has walls that are approximately 2.5 inches thick or greater. The research reported in this RIL is limited to the rupture of such large pipes because they will generate the most severe LOCA loads which, when combined with SSE loads, present serious design and retrofit problems. It is recognized that the break of a smaller pipe may be more probable, and that such a small LOCA may pose larger risks to the plant. However, the scope is limited to the large LOCA defined above in order to address the immediate NRC need for research to support licensing decisions. It is believed, nonetheless, that the models and computational procedures developed for the large LOCA can be extended to the assessment of smaller LOCAs.

Two distinct methodologies involving different disciplines are invoked to evaluate the probability of an earthquake and large LOCA occurring simultaneously. That methodology depending on probabilistic fracture mechanics investigates what is termed direct seismically-induced large LOCA. That methodology depending on systems analysis and event trees/fault trees investigates what is termed indirect seismically-induced large LOCA.

For direct seismically-induced large LOCA, only fatigue crack growth resulting from the combined effects of thermal, pressure, seismic, and other cyclic loads was considered as the mechanism leading to complete pipe rupture as a consequence of earthquakes. The water hammer mechanism was not considered because it has never been observed in PWR primary systems. Likewise, stress corrosion is another possible mechanism, but it was excluded from consideration because stress corrosion problems have not been observed in PWR primary systems, and because the coolant water chemistry and level of calculated residual stress are not conducive to stress corrosion.

In addition to direct pipe fracture as a result of fatigue, a guillotine pipe fracture may be caused by an indirect means; that is, a seismic event may cause a failure in some component which in turn causes a primary piping failure. Electrical and structural failures, explosions, missiles, and fires were examined as potential causes for an indirectly induced LOCA. However, only those event sequences leading to the guillotine break of the primary coolant piping are considered in the event combination assessment.

## Results

The results reported below are explicitly applicable to Zion, Unit 1 since the seismic hazard, transient history, NSSS and plant configuration employed in this investigation are based on Zion, Unit 1 data. While

Zion, Unit 1 features are representative of many plants, additional study is needed to generalize these findings to other situations, particularly to BWRs. These findings do not consider the impact of design, construction and assembly errors. The principal results are:

1) Considering only fatigue crack growth, the probability of a simultaneous large LOCA and an earthquake is on the order of $10^{-13}$ during the 40-year plant life.

2) Limited sensitivity studies in which crack size distributions were varied, seismic loads were varied and the impact of in-service inspection and leak detection were varied indicate that the estimate in item 1 above may vary by several orders of magnitude under extreme assumptions.

3) Considering only fatigue crack growth, the probability of a large LOCA is on the order of $10^{-12}$ over the 40-year plant life. This is contrasted with item 1 above, in that here the large LOCA may be induced by any transient except water hammer. While not a stated objective of the investigation, it has been found that a double-ended guillotine break in primary system piping due to fatigue crack growth is an extremely unlikely event under any transient conditions normally postulated in PWR primary systems.

4) Considering only fatigue crack growth, the probability of a leak occurring during the 40-year plant life is on the order of $10^{-6}$. Other factors such as stress corrosion cracking or corrosion fatigue will undoubedtly make this number larger. Once again, while not a stated objective, this finding came to light from through-wall crack calculations.

5) Indirect seismically-induced LOCA probabilities cannot at this stage be stated as confidently as direct seismically-induced LOCA probabilities. Nonetheless, preliminary computations including earthquakes up to 3 times the SSE indicate that seismically-induced structural failures which threaten the integrity of the primary system piping have probabilities of the order of $10^{-3}$ to $10^{-5}$ over the 40-year plant life. The above-quoted probability must then be combined with the probability that structural failure will cause a double-ended guillotine break. For some failure modes treated, such as containment overturning and collapse of the steam generator supports, this latter probability is believed to be close to unity. However, these failure modes are so severe in their consequences, that the double-ended guillotine break of the primary system piping may be of secondary importance. Seismically-induced fires, explosions, missiles, mechanical and electrical failures are not major contributors to primary system pipe failure.

The independent Peer Review Panel of five nationally-known experts contracted to study and offer critical evaluative comments on this research has stated to the ACRS subcommittee on Combination of Dynamic Loads as follows with regard to direct seismically-induced LOCA:

> "The reported results of the de-coupling study show two answers which are of large potential interest:
>
> (a) the increase of large LOCA probability by incidence of earthquake loads (over that of large LOCA associated with crack growth induced by non-seismic sources) is relatively small, and
>
> (b) the ratio of occurrence of through-wall cracks (possibly detectable leakage) to occurrence of large LOCA is extremely large.

There are plausibility reasons to suggest that these results might not be changed significantly by further study.

However, the estimated probability of earthquake-induced large LOCA of $4 \times 10^{-13}$ per plant life is deemed to be subject to large uncertainties. Its extremely low value makes more urgent the reevaluation of the assumptions of the study."

Evaluation

The following are believed to be the significant conclusions which may and should have near-term impact on licensing:

1) It is concluded from results 3 and 4 that for reasonable and representative conditions relating to fatigue crack growth in primary system piping, through-wall cracks are about a million times more likely to occur than double-ended guillotine breaks. This appears to offer substantial quantitative support in a probabilistic format for the leak-before-break hypothesis. This estimate may be less sensitive to input assumptions than other results since it is the ratio of two related computations of probabilities.

2) Fatigue crack growth due to all transients, including earthquakes, is an extremely unlikely mechanism for inducing large LOCA. The contribution of earthquakes to the occurrence of this unlikely event is a few percent of the total probability. Thus, fatigue-induced large LOCAs are very remote events, and earthquake-induced large LOCAs by fatigue are even more so.

3) An upper bound estimate of the probability of asymmetric blowdown loads (resulting from rupture of in-cavity piping) due to direct and indirect mechanisms is $10^{-4}$ over the 40-year plant life, the primary contribution to this estimate being indirect seismically-induced asymmetric blowdown. It is felt that the best estimate of the probability is several orders of magnitude lower. It is believed that additional study of indirect seismically-induced asymmetric blowdown has the potential for reducing the upper bound because of the very limited number of scenarios leading to asymmetric blowdown.

John O'Brien of the Mechanical Engineering Research Branch (x74284) can provide additional details on this research.

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Robert B. Minogue, Director
Office of Nuclear Regulatory Research

<u>REFERENCE</u>

1. NUREG/CR-1889, "Large LOCA-Earthquake Combination Probability Assessment - Load Combination Program, Project 1 Summary Report," January 1981, prepared by Lawrence Livermore National Laboratory (FIN A-0133).

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/S/ D. F. Ross/for
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RECORD NOTE: This RIL was reviewed and approved in NRR and the Division of Systems and Reliability Research.

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Summary

This RIL describes work performed for the U. S. Nuclear Regulatory Commission by the Load Combinations Program at Lawrence Livermore National Laboratory since March 1979. The results indicate that the probability of a double-ended guillotine break of the primary system piping during an earthquake is extremely small. Qualitative support in a probabilistic format for the leak-before-break hypothesis is one major finding.

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