UNITED STATES
NUCLEAR REGULATORY COMMISSION
[illegible], D.C. [illegible]5

March 2, 1982

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THRU: Steven A. Varga, Chief, ORB#1, DL SV

FROM: David Wigginton, PM, ORB#1, DL

SUBJECT: DAILY HIGHLIGHT

Zion Station Unit No. 1

On February 25, 1982 while preparing for tube inspection of the steam generators in Zion Unit No. 1, station personnel discovered pieces of a hinge, one about 24 inches long and 2 inches wide, in the plenum area (primary side) of the 1B steam generator. Other smaller pieces were discovered in the 1D steam generator. The hinge is believed to be part of a tube nozzle cover which blocked the nozzles during the previous steam generator inspection. These covers are made of aluminum which chemically dissolved since the last refueling leaving only the hinges. During the April 1981 startup of Unit 1, a loose parts monitor alarm was received on steam generator 1D but later stopped. The licensee evaluated the loose parts monitoring signals and determined that they did not represent a problem for continued operation. We have also been informed that the loop "D" low flow trips had been set nonconservatively for the period April 10 thru May 9, 1981 potentially due to the flow blockage on the primary side of the steam generator.

The licensee is developing plans to further investigate the presence of foreign objects in the primary cooling system. Region III is following the investigation.

DLWigginton
David Wigginton, Project Manager
Operating Reactors Branch No. 1
Division of Licensing

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Probabilistic safety study of Zion Station

Following the TMI incident, Commonwealth Edison, as one of the utilities singled out for "near-in-site" studies, developed a comprehensive study that went beyond what was needed to respond to the NRC, and will have ongoing uses for the results for training and future design evaluations

By GEORGE T. KLOPP, Commonwealth Edison

The closing half of the year 1979 saw an intense flurry of activity on the part of the U.S. Nuclear Regulatory Commission (NRC) in response to the Three Mile Island (TMI) incident. Active licensing projects were shut down while regulatory staff members became involved with a major review and augmentation of existing regulations. Almost lost in the sea of bulletins and orders, a small group of utilities were further smitten with "near-in-site" study requirements. The NRC staff developed the idea that this select group of plants, including Commonwealth Edison's Zion Station, might represent an undue share of reactor risk as a result of site area demography.

In December 1979, Commonwealth Edison was asked to accomplish three tasks relative to Zion Station:

1. Evaluate the feasibility of installing new features to mitigate the effects of full core meltdowns, irrespective of their likelihood.
2. Evaluate other measures that might reduce the likelihood of such meltdown events.
3. Evaluate interim measures to reduce public risk pending the outcome of the first two tasks.

Commonwealth Edison was given 60 days to respond and was asked to have designs for core ladles and filtered vented containment systems, as a minimum, evaluated in that time. At the end of the 60-day period, Commonwealth Edison was able to produce a limited scope assessment of the Zion Station risk, which showed that risk to be far lower than originally perceived. It also generated a great deal of information that clearly demonstrated the need for substantially more work before any firm results could surface.

The Zion Probabilistic Safety Study represents that additional work and provides a clear answer to the NRC staff. As the study concept matured, early in the process, three basic purposes were established. They were:

1. To provide an up-to-date assessment of the public risk associated with the operation of Zion Station as currently constituted and operated.
2. To identify the dominant contributors to that risk.
3. To develop and evaluate mitigating features based on the physical parameters associated with the dominant risk contributors.

As completed, the Zion Study goes far beyond what might be needed to respond to the NRC. More will be said later about the future uses of this study.

Study scope and concept

The Zion Probabilistic Safety Study owes much to the basic work done in the Reactor Safety Study (WASH-1400) and much to the responsible criticism of that work by the Lewis Committee. However, the Zion Study extends the scope and depth of its risk analyses beyond WASH-1400 and represents a significant advance in the state of the art in risk assessment of nuclear power plants. Significant advances have been made in the analyses of plant systems and site consequences. Major breakthroughs have been made in the areas of containment analyses and the analyses of important external events. The final report on the Zion Study consists of nearly 6000 pages of material in ten volumes.

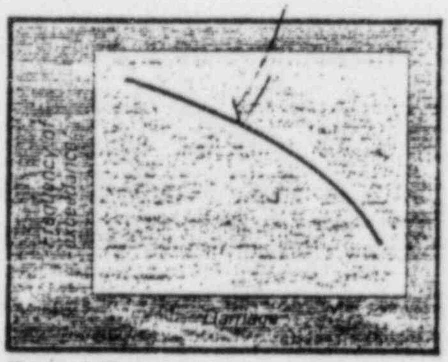
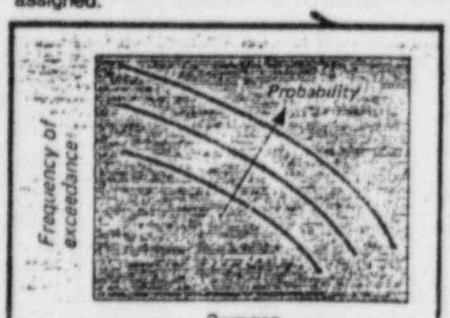


Figure 1. First level risk curve.

Figure 2. Second level risk curves, each of which has a probability, or confidence level assigned.



The basic tool used to structure the Zion Study is probabilistic risk analysis or PRA. PRA has enjoyed a widespread application in the defense and aerospace industries for some time. As noted before, the first large-scale use of PRA in civilian nuclear power applications was WASH-1400. Since then, the continued use of PRA in this application has been endorsed by various industry and regulatory leaders and by the President's Commission on the Accident at TMI (Kemeny Commission).

Probabilistic risk assessment is an intensely disciplined approach to evaluating complex technical constructions. The term "risk" itself requires careful definition. A typical dictionary definition reads "exposure to the chance of injury or loss." Two key concepts are explicit in this definition. They are the "chance" or likelihood and the "injury" or "loss" or damage. The PRA concept of risk involves both of these concepts and seeks to quantitatively establish the relationship between likelihood and damage. In a society of any type people tend to work towards some perceived level of risk which is acceptable in terms of defined standards, intuitive judgment, or more commonly, tacit societal acceptance. PRA now offers the tools to more explicitly define risk, at least within some defined scope, and allows more informed

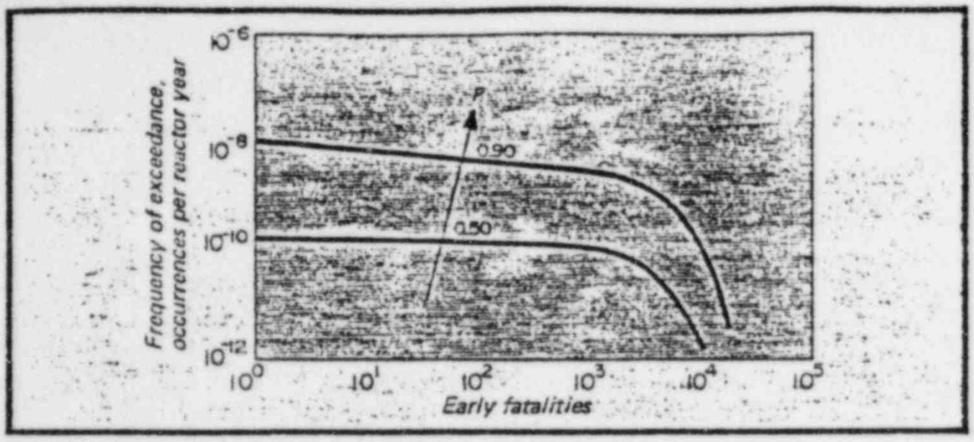


Figure 3. A family of curves showing the risks of early fatalities is generated from the curves of Figure 2.

judgments to be made relative to various risks.

With this background, we can proceed to examine the specifics of the Zion Study in more detail. As with any PRA structure, it is centered around three basic questions.

1. What can go wrong?
2. How likely is it that this will happen?
3. If it happens what are the consequences?

The answers to these questions can be listed in an orderly manner as shown in Table 1:

Scenario	*Likelihood*	*Consequences*
S_1	L_1	X_1
S_2	L_2	X_2
.	.	.
.	.	.
S_n	L_n	X_n

The scenarios are descriptions of situations defined in response to the first of the three questions. The likelihood and consequences are responses to the second and third questions respectively. It is simple, given the responses, to arrange the scenarios in order of increasing severity of consequences. Also, it is possible to assign to each scenario the cumulative likelihood of all subsequent scenarios, starting at the bottom of the table. This allows one to assess the likelihood of equalling or exceeding consequence X_2 as the sum of $L_2+L_3+\ldots L_n$. This "frequency of exceedance" format results in a first level risk curve as shown in Figure 1. This curve is similar to that portrayed in WASH-1400.

Careful consideration of the comments on WASH-1400, particularly those of the Lewis Committee, and of the nature of any such study reveals that a single curve does not represent risk adequately. The basis for this conclusion stems from the significant uncertainties inherent in the quantified relationships defined by any such curve. The state of knowledge and the data available for any such PRA do not permit exactly defined results. Therefore, to be honest, we must characterize our uncertainty at each step in a PRA and portray the combined uncertainty in our results. This leads to a family of curves as shown in Figure 2 wherein each curve has a probability, or confidence level, assigned.

Deriving such curves for Zion Station responds to the first of our three purposes, the establishment of a basic risk assessment. The second purpose, identification of dominant contributors to risk, falls directly out of this work. The third purpose, the development and assessment of mitigating features, requires additional work. In a broad sense then, the Zion Study involved six major work areas:

1. Plant systems and equipment analyses.
2. Containment analyses.
3. Site consequences analyses.
4. External events analyses.
5. Risk integration and evaluation.
6. Mitigating features assessment.

Plant systems and equipment

This work area has two basic purposes. First of all, it identifies and defines those scenarios or sequences of events which could lead to core melt conditions. Secondly, it develops the quantification of the likelihood of each such scenario, and it groups similar such events into plant event states with collected likelihoods. Drawing on the basic event tree and fault tree techniques developed in WASH-1400, and on programs like the NRC's Integrated Reliability Evaluation Program (IREP), we were able to structure a series of logic models of Zion Station. Each such model represents a myriad of possible plant responses to a particular type of initiating events. Our search for a comprehensive list of initiating events, or plant perturbations, took us to Final Safety Analysis Report (FSAR), generic operating experience data and Zion specific operating experience. In addition, both pure brainstorming and a master logic diagram were used to assist in making a list comprehensive. The result was a list of nearly 60 possible events. A careful review of these revealed that they could be grouped into 13 categories of initiating events. Each was used to start a separate event tree. The likelihood of each of these initiating event categories was derived from the generic data base and modified, where appropriate, by Zion specific data using Bayesian techniques. Special attention was paid to uncertainty.

The event tree and fault tree construction treated human error, common cause failures and system dependencies using state of the art techniques. A new approach was taken relative to electric power availability. Each of the 13 event trees was quantified for each of the eight possible states of electric power availability. This quantification involved the development of a component level data base using the technique described above for initiating events. The result was a mass of possible event tree end point frequencies. Nearly 10,000 such values were derived, each representing a potential core melt sequence. As with the initiating events, it proved possible to collapse this mass of information into categories. In this case, 21 plant event sequence categories were employed, each of which represents a unique set of characteristics in terms of core melt progression, mass and energy release to the containment, and containment active safeguards status.

Mathematically, the initiating event frequencies were found to resemble a 13-component row vector. Similarly, the plant event sequence categories could be characterized as a 13 by 21 matrix. This representation was found invaluable later in the study.

Containment analyses

The work in this area represents a major advancement over that done in any previous study, including WASH-1400. The Zion Study included a great deal of original work and some specific experimental programs aimed at understanding specific phenomena related to a variety of core melt events. It was found that these phenomena were, in many cases, very sens tive to the sequence being considered. It was found that the study's experimental results, the results of other U.S. experiments and the results of foreign experiments could be correlated by analytical models. Some of the areas considered were steam explosions, reactor vessel failure modes, hydrogen generation and ignition, steam spiking, and debris bed cooling.

These phenomenological investigations were used as inputs to and verification checks on a major program of containment transient analyses. These analyses were run with "best estimate" analytical models and with a variety of other models as well to provide a spectrum of results. Furthermore, a major effort was made to vary input parameters to all these models to provide sensitivity studies yielding an even wider spectrum of results. The results were all compared to an ultimate containment capability having a best estimate value of 149 psia. This value was derived from a realistic finite element containment analysis which included consideration of penetrations and hatches.

Thus far, the work was deterministic in nature. Converting this massive amount of technical information into a probabilistic format was a unique challenge. The method used was an event tree. As many of the issues in containment response did not involve system behavior, the nodal questions in this event tree tended to involve the various phenomena and containment success or failure resulting therefrom. For example, one question would read "Does hydrogen burn at this point?" The next question would be "Does the resulting pressure exceed the containment capability?" The questions were arranged in approximate chronological order to track the core melt and containment response. The 19 nodal questions were quantified by reference back to the phenomenological work and the transient analyses. Uncertainty was based on assessments of these same areas including the variations in analytical models and sensitivity studies.

Two key factors came to light. First of all, for the vast majority of coremelt cases, a coolable debris bed is formed even after the reactor vessel has failed. Second, for over 99% of the coremelts considered, no containment failure is predicted.

The last area involved the collapse of the sequences in this event tree into release categories. Basically, the WASH-1400 source terms were employed in this study. Eleven release categories were employed which resulted in a 21 by 11 matrix representation.

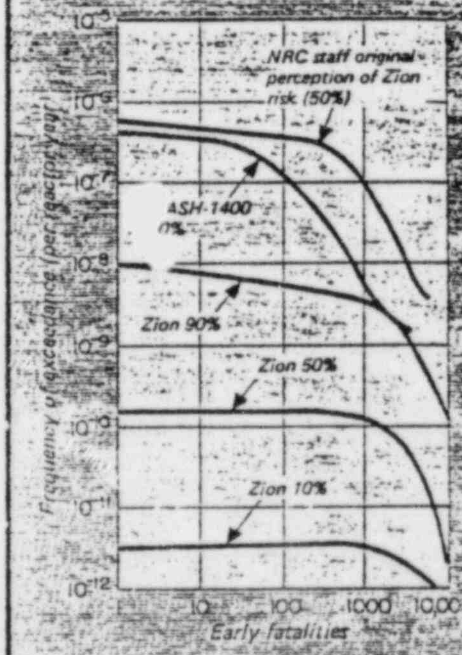
Site consequence analyses

The work in this area employed an updated version of the WASH-1400 CRAC code. The update included provisions for varying plume direction over time and and for varying the direction of evacuation to account for local transportation networks. Basically, the work involved an elaborate computer model, using Monte Carlo simulation to relate each release category to the likelihood of varying degrees of damage. Damage was measured using five health effects, foremost of which was early fatalities. Five separate matrices were developed, one for each health effect.

External events

The treatment of external events in the Zion Study involved consideration of seismic events, fires, floods, tornadoes, aircraft crashes and other similar events. Scoping considerations showed that only seismic events and fires warranted extensive treatment. Fires in turn were shown to have an insignificant impact on risk at Zion. Seismic events were not easily dismissed and the analysis technique is of interest. Basically, the analyses involved an assessment of the seismicity of the site, including uncertainty, an assessment of the fragility of plant structures and components under various seismic accelerations, including uncertainty, and the formulation of Boolean expressions for coremelt scenarios and release categories given failure of structures and systems. Then, using probabilistic arithmetic, the seismicity and fragilities were combined through the Boolean logic to arrive at frequencies for various release categories including uncertainty. This data could then be factored directly into the work described previously by modifying the matrices as appropriate.

Figure 4: Perspective on Zion risk



Risk integration

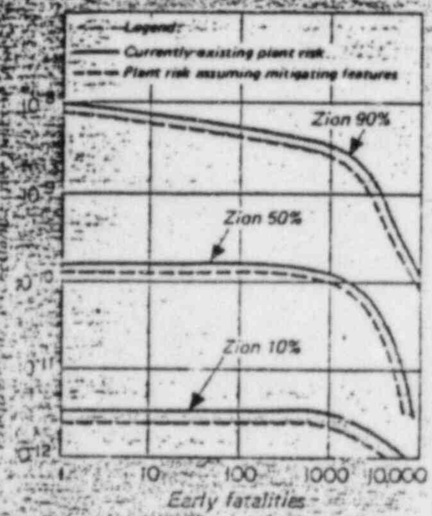
Risk integration essentially took the form of a matrix multiplication operation. It led, conceptually, to a table similar to Table 1 but one in which the discrete values were replaced by distributions to include uncertainty. One such table can be derived for each health effect in principle. In reality, curves of the form of Figure 2 were generated and presented as results. Figure 3 is a sample of those results showing the early fatalities curves. The curves are read by selecting a damage level and reading up to the confidence level of interest, then left to the frequency of exceedance. In English, we can say, for example, "We are 90% confident that the frequency with which an event will occur at Zion that will cause 100 early fatalities is no greater that about 4×10^{-9} per reactor year of operation."

In assessing the risk, one of the tasks is to identify the dominant contributors to that risk. In the case of Zion, three events out of the tens of thousands considered dominate risk. In decreasing order of importance they are:

1. Seismic induced core melt.

2. The double rupture failure of the disks on two, series, motor-operated, normally

Figure 5. Evaluation of new features to mitigate effects of core melts shows them to be of marginal value.



closed gate valves between the Reactor Coolant System and the Residual Heat Removal System.

3. The total loss of all onsite and offsite electric power coincident with the failure of the turbine-driven auxiliary feedwater pump train and the inability to operate the diesel driven containment spray pump train.

The design of Zion Station included provisions to allow the plant to withstand seismic events more severe than the maximum recorded earthquake in northern Illinois. The earthquake that causes core-melt is at least three times more severe than that chosen as the design basis for the plant. Given that Zion is located in an area characterized as having "low seismicity" and given the substantial design margin noted above, it can be argued easily that classical failures in the plant design and operation must offer very little risk to permit seismic events to dominate the total risk. For perspective, the seismic events of interest most likely correlate to the San Francisco (1906) or Alaska (1968) earthquakes or worse. It should also be noted that the earthquake induced events do not directly fail the containment building. Such a failure is not expected to occur for at least 12 to 14 hours after the event.

An additional perspective on the Zion risk can be obtained by superimposing the WASH-1400 risk curve and the original NRC perception of Zion on the results shown earlier for early fatalities. Figure 4 illustrates this perspective. Note that the Zion 50% curve, labelled 0.5, is comparable to these other two 50% curves.

Mitigating features

As requested by the NRC, a detailed evaluation of new features to mitigate the effects of core melts was made. The Zion Study carefully considered the following:

1. Core ladles to retain the molten debris after reactor vessel failure thereby preventing failure of the concrete basemat.

2. Filtered vented containment systems to filter and release post-melt containment steam and gases thereby preventing an over-pressure failure of the containment building.

3. A modification to the existing diesel driven containment spray system to perform the same function as the filtered vent without any releases.

4. Hydrogen control systems.

Using the PRA tools described earlier, the effect of each of these features, except hydrogen control, was evaluated. The core ladle was found to offer no perceptible risk reduction due largely to the existence of effective debris bed cooling at Zion. The filtered vented containment system and the modified spray system at best provided only marginal reduction in the already low levels of risk. Figure 5 illustrates these results. The hydrogen control concept was dropped from consideration when it was found that hydrogen posed no significant threat to the containment.

Conclusion

The basic conclusions are obvious from the results. Zion does not, by any available standard, pose an undue public risk. The effectiveness of new mitigating features is, at best, marginal at Zion and Zion should not be singled out for further consideration of such features.

Beyond this obvious set of responsive conclusions to the original NRC interest, the Zion study can provide Commonwealth Edison with an ongoing resource for training, evaluating plant modifications, evaluating changes in technical specifications, and evaluating designs for future plants. Future uses of the study are currently under scrutiny. However, Commonwealth Edison has gained a much deeper insight into Zion Station as a result of this study. This alone has prompted consideration of similar studies on other Edison nuclear plants.

Finally, we must acknowledge a point made in the German risk study. We are evaluating extremely rare events. We have shown that to be the case. However, the degree of effort expended and the fact that we discuss such events tends to have a reverse impact. There are those, who, seeing the subjects addressed in print, automatically ignore any perspective offered and elevate these rare events, consciously or otherwise, into the realm of everyday happenings. This is unfortunate and we have no ready-made solution to the problem. However, it is hoped that the detail and candor in the Zion study and the perspectives offered will overcome this tendency for the majority of readers. END