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PRA Studies: Results, Insights, And Applications

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PRA STUDIES: RESULTS, INSIGHTS AND APPLICATIONS

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INTRODUCTION

Probabilistic Risk Assessment (PRA) is a combination of logic structures (event trees and fault trees) and analytical techniques that can be used to estimate the likelihood and consequences of events that have not been observed because of their low frequency of occurrence. The first major development and application of PRA techniques specifically to nuclear power plants was in the Reactor Safety Study (WASH 1400)[1], published in October 1975.

This report became the subject of considerable controversy principally because of its new techniques and its complex, multidisciplinary nature, and because of the prevailing controversy about nuclear power. In June 1977, at the request of the United States Congress, the Nuclear Regulatory Commission (NRC) established a Risk Assessment Review Group to clarify the achievements and limitations of WASH 1400. This group, chaired by Professor Harold Lewis of the University of California - Santa Barbara, filed a report [2] in September 1978 which concluded that WASH 1400 was "a substantial advance over previous attempts to estimate the risks of the nuclear option." The report criticized some of the analytical techniques used in the study and concluded that the uncertainty ranges on results were larger than stated in WASH 1400. However its strong recommendations that PRA techniques be used to reexamine existing NRC regulations and practices to make them more rational left little doubt that the PRA approach was extremely useful.

Unfortunately, the findings and recommendations of the Lewis Report were misinterpreted by the NRC Commissioners in a January 1979 policy statement[3] that withdrew Commission support for the Executive Summary of WASH 1400 and essentially precluded the use of PRA techniques in regulatory decisionmaking.

However, attitudes concerning PRA changed dramatically following the March 1979 accident at Three Mile Island and in the following years as many people came to understand the value of the risk insights contained in WASH 1400. Two of the major investigations of the TMI accident, the report of the President's Commission (Kemeny Report)[4] and the report of the NRC Special Inquiry Group (Rogovin Report)[5] strongly supported the increased use of PRA techniques in the NRC regulatory process. In the years since the TMI accident, there has been a rapid expansion in the use of PRA in the United States and in several other countries.

PRA STUDIES COMPLETED TO DATE

As of mid-1983, twenty-two nuclear plant PRA studies have been completed, nineteen on nuclear units located in the U. S. and three on nuclear units located in other countries. These twenty-two units are listed in Table 1, with information on plant design and PRA type or sponsorship. The completed studies listed in Table 1 cover a wide spectrum in objectives, scope, technical sophistication and resources applied. Direct comparisons of results should therefore be made with great caution.

Two of the plants listed in Table 1, SURRY-1 and Peach Bottom-2, were analyzed in the Reactor Safety Study, WASH 1400. This study was sponsored by the U.S. Atomic Energy Commission (later the Nuclear Regulatory Commission) to estimate the public risks that could result from accidents in U.S. commerical nuclear power plants. The objective of the study was to make a realistic quantitative estimate of these risks and to compare them with other, non-nuclear societal risks. As is now well known, WASH 1400 broke much new ground in the development of quantitative risk assessment techniques. All PRAs performed since then use the same methodology although they have incorporated improvements in some of the specific techniques involved.

Four of the completed studies, those for Sequoyah-1[6], Oconee-3[7], Calvert Cliffs-1[8], and Grand Gulf-1[9], were performed under the auspices of the US NRC's Reactor Safety Study Methodology Applications Program (RSSMAP). The objectives of this program were to apply the methods developed in WASH-1400 to reactor and containment designs different from those studied at Surry and Peach Bottom, in order to determine the sensitivity of dominant accident sequences to these plant-to-plant variations. These limited-scope studies did not include external events or risk estimates, and involved only a few man-years of effort.

TABLE 1

PRA STUDIES COMPLETED AND PUBLISHED

PLANT	OPERATING LICENSE	Mwe	NSSS	A/E	CONTAINMENT	SPONSOR (PROGRAMME)
Arkansas 1	1974	836	B&W	Bechtel	Dry Cylinder	NRC (IREP)
Biblis B	1976	1240	Siemens	KWU	Dry Cylinder	BMFT
Big Rock Point	1962	71	GE	Bechtel	Dry Sphere	Utility
Browns Ferry 1	1973	1065	GE	TVA	Mark I	NRC (IREP)
Calvert Cliffs 1	1974	845	CE	Bechtel	Dry Cylinder	NRC (RSSMAP)
Crystal River 3	1976	797	B&W	Gilbert	Dry Cylinder	NRC (IREP)
Grand Gulf 1	(1983)	1250	GE	Bechtel	Mark III	NRC (RSSMAP)
Indian Point 2	1973	873	W	UE&C	Dry Cylinder	Utility
Indian Point 3	1975	965	W	UE&C	Dry Cylinder	Utility
Limerick	(1985)	1055	GE	Bechtel	Mark II	Utility
Millstone 1	1970	652	GE	Ebasco	Mark I	NRC (IREP)
Oconee-3	1973	860	B&W	Duke	Dry Cylinder	NRC (RSSMAP)
Oconee-3*	1973	860	B&W	Duke	Dry Cylinder	Utility
Peach Bottom 2	1973	1065	GE	Bechtel	Mark I	NRC (WASH 1400)
Ringhals 2	1975	800	W	SSPB & Gibbs Hill	Dry Cylinder	SSPB
Sequoyah 1	1981	1148	W	TVA	Ice Condenser	NRC (RSSMAP)
Shoreham 1	(1983)	819	GE	S&W	Mark II	Utility
Sizewell B	(-)	1200	W	Bechtel	Dry Cylinder	NNC
Surry 1	1972	788	W	S&W	Dry Cylinder	NRC (WASH 1400)
Susquehana*	(1983)	1050	GE	Bechtel	Mark II	Utility
Yankee Rowe	1960	175	W	S&W	Dry Sphere	Utility
Zion	1973	1040	W	S&L	Dry Cylinder	Utility

* Completed, but not yet publicly available

The NRC's interim Reliability Evaluation Program (IREP) has provided four PRA studies as of mid-1983, those for Crystal River-3[10], Arkansas Nuclear One Unit 1[11], Browns Ferry-1[12], and Millstone-1[13]. A fifth IREP report, on Calvert Cliffs-1 is expected to be published in the near future. Two objectives of the IREP studies were to identify those accident sequences that were dominant contributors to core melt probability and to expand the cadre of experienced PRA practioners in the U.S. IREP evaluations were limited in scope in that they were carried forward only to the point of estimating core melt probabilities. They did not consider external events, their containment analysis was limited, and risk estimates were not included in the calculations.

Seven utility-sponsored PRA studies have been completed in the U.S. as of early 1983 for Yankee Rowe[14], Big Rock Point[15], Zion[16], Indian Point-2 and 3[17], Shoreham[18], and Limerick[19]. PRAs for the Oconee-3 and Susquehana units have been completed and reports are expected to be publicly available in the near future. The utility-sponsored PRAs are generally more complete than the NRC-sponsored studies, in that they include consequence calculations and containment response analyses as well as the systems analyses needed to obtain estimates of core melt probability. The Zion Study has been estimated to have consumed about forty man-years of effort, including large developmental tasks in the modeling of physical phenomena.

The three units outside the U.S. for which PRA studies have been completed and published are Biblis B[20] in West Germany, Ringhals[21] in Sweden, and a report for the proposed Sizewell B PWR[22] in the United Kingdom. The Ringhals study was limited to the identification of dominant core melt sequences and the equipment and procedural failures that contribute to these dominant sequences, with special emphasis on procedures and the timing of events; further work is now going forward to cover containment behavior and fission product release. The Sizewell B report includes the systems analyses needed for core melt probability estimates, containment response calculations, and a fission product source term analysis. The Biblis-B report scope is comparable to that of WASH 1400 as it includes core melt probability estimates, containment response calculations with source term estimates, and consequence calculations. In addition to internal initiating events, the effects of external events such as earthquakes, aircraft crashes, explosions and floods were assessed for Biblis-B.

Presented below is information based on completed PRA studies in the following subject areas:

- Results - with emphasis on core melt probability estimates and accident sequences that are the principal contributors to core melt

- Insights - Conceptual, overall risk, accident sequences, system dependencies, human interactions and regulatory considerations

- Applications - Existing or possible applications for both industry and regulators

RESULTS OF COMPLETED PRA STUDIES

The quantitative estimates of public risks from PRAs are not nearly as important as the engineering and safety insights gained from the structured logic and thought processes involved in arriving at the results. The numerical results presented below are a summary of core melt probability estimates, some limited compilations of accident sequences that principally determine the frequency of core melt and the frequency and magnitude of public risks for a few selected plants, and some observations on these core melt probabilities and accident sequences.

CORE MELT PROBABILITIES

Table 2 presents the core melt probability estimates from the twenty PRAs completed and publicly available as of early 1983. Direct comparisons of these numbers should be made with caution because the numerical values were generated using somewhat different models, assumptions and degrees of technical sophistication in the analyses. The range of core melt probability estimates covers about three orders of magnitude from 1×10^{-6} per year to 2×10^{-3} per year.

DOMINANT SEQUENCES

One of the results of a PRA study is the identification of a small number of accident sequences that represent the dominant contributors to core melt or to risk. Dominant sequences from several PRAs have been categorized and compiled in Reference 23, and the results of the compilation, in terms of the relative contributions to core melt probability, are shown in

Figure 1. Figure 2 is the end result of a similar process of categorizing and compiling those sequences representing major contributors to significant releases of radioactive materials. PWRs included in the compilation of Figures 1 and 2 are are Arkansas-1, Oconee-3, Sequoyah-1, Surry and Zion; BWRs in the compilations are Grand Gulf, Peach Bottom-2 and Limerick.

Based on this limited sample of dominant sequence categories from the eight PRAs cited above, the following observations are made:

- small LOCAs with failure of safety injection are the largest contributors to PWR core melt probability; transients with failure of long term decay heat removal are the largest contributors to BWR core melt probability

- The split between LOCA and transient contributors to core melt probability is about 60:40 for PWRs and about 10:90 for BWRs (LOCA:Transient)

- Figure 2 shows that the largest single functional contributor to significant releases of radioactive materials is the failure of long term decay heat removal. These failures are associated with LOCAs in PWRs and transients in BWRs.

TABLE 2

PRA RESULTS - CORE MELT PROBABILITIES[1]

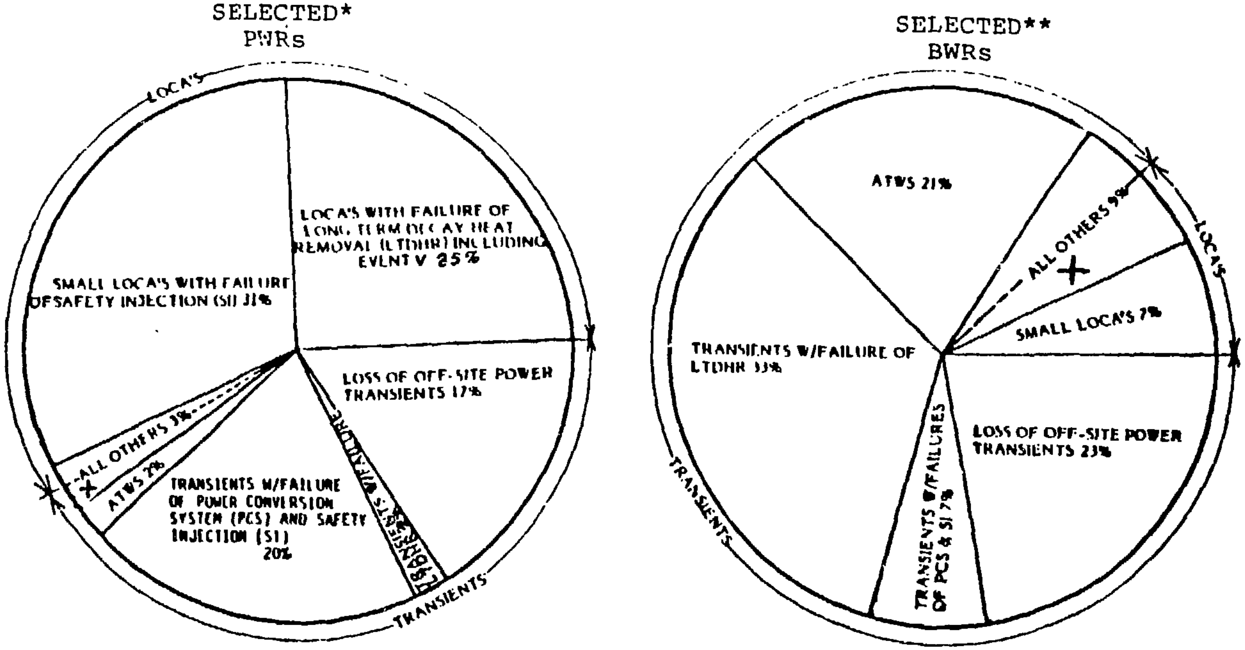
PLANT	POWER (MWe)	TYPE, NSS	PRA/DATE	CORE MELT[2] PROBABILITY, $(YR)^{-1}$
Arkansas-1	836	PWR,B&W	IREP, 1981	5×10^{-5}
Biblis B	1240	PWR,KWU	DRS, 1978	4×10^{-5}
Big Rock Point	71	BWR, GE	SAI/Wood Leaver, 1981	1×10^{-3}
Browns Ferry 1	1065	BWR, GE	IREP, 1981	2×10^{-4}
Calvert Cliffs 1	845	PWR, CE	RSSMAP, 1982	2×10^{-3}
Crystal River 3	797	PWR, B&W	IREP, 1980	4×10^{-4}
Grand Gulf 1	1250	BWR, GE	RSSMAP, 1981	4×10^{-5}
Indian Point 2	873	PWR, W	PLG, 1982	2×10^{-4}
Indian Point 3	965	PWR, W	PLG, 1982	6×10^{-5}
Limerick	1055	BWR, GE	SAI, 1981; NUS, 1983	3×10^{-5}
Millstone 1	652	BWR, GE	IREP, 1982	3×10^{-4}
Oconee 3	860	PWR, B&W	RSSMAP, 1980	8×10^{-5}
Peach Bottom 2	1065	BWR, GE	WASH 1400, 1975	3×10^{-5}
Ringhals 2	800	PWR, W	NUS, 1983	4×10^{-6}
Sequoyah 1	1148	PWR, W	RSSMAP, 1981	6×10^{-5}
Shoreham 1	819	BWR, GE	SAI, 1983	4×10^{-5}
Sizewell B	1200	PWR, W	W, 1982	1×10^{-6}
Surry 1	788	PWR, W	WASH 1400, 1975	6×10^{-5}
Yankee Rowe	175	PWR, W	EI, 1982	2×10^{-6}
Zion	1040	PWR, W	PLG, 1981	4×10^{-5}

Notes for Table 2

1. Large uncertainties are associated with the core melt probability estimates listed in this table. Also, these estimates were generated using widely varying methods and assumptions.

2. Values listed are median values or point estimates.

FIGURE 1 MAJOR CONTRIBUTORS TO CORE MELT FREQUENCY



+ "All Others" contain roughly equa
of LOCA and transients

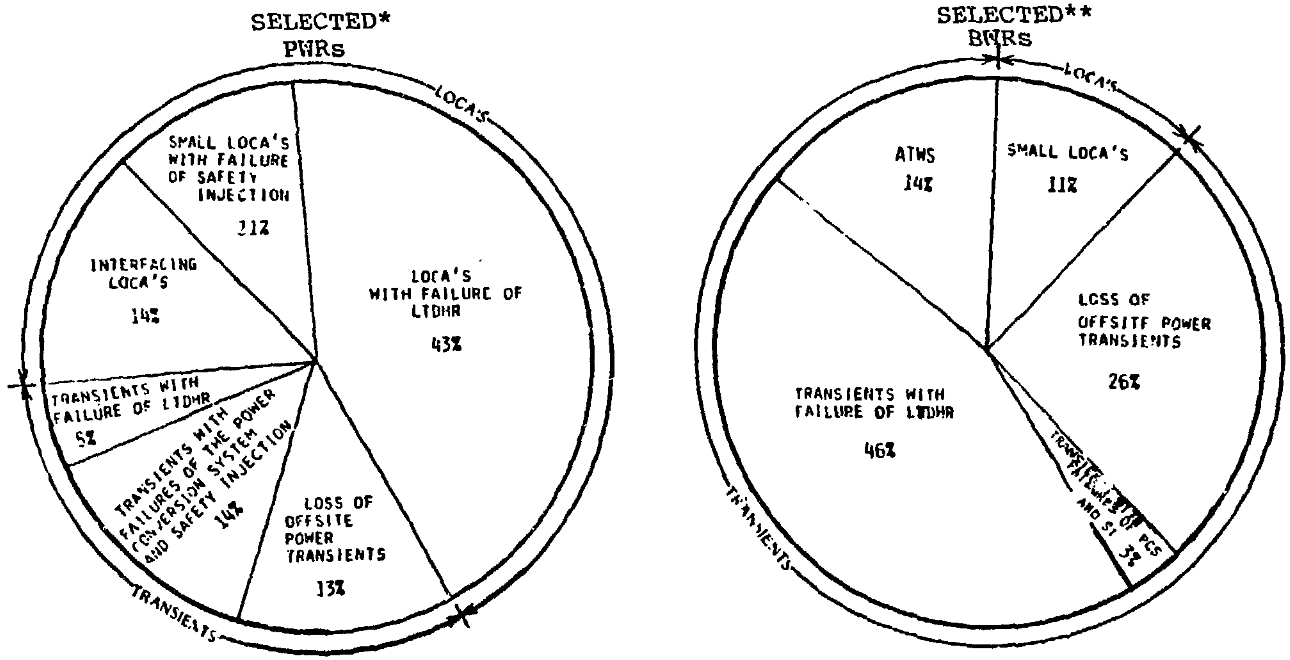
* Arkansas-1, Oconee-3, Sequoyah-1,
Surry, Zion

** Grand Gulf, Limerick, Peach Bottc

NOMENCLATURE:

LOCA	Loss of Coolant Accident
SI	Safety Injection
ATWS	Anticipated Transients Without Scram
PCS	Power Conversion System
LTDHR	Long Term Decay Heat Removal
Event V	Interfacing Systems LOCA

FIGURE 2 MAJOR CONTRIBUTORS TO SIGNIFICANT RADIOACTIVITY RELEASES



*Arkansas-1, Oconee-3, Sequoyah-1, Surry, Zion

** Grand Gulf, Limerick, Peach Bottom-2

NOMENCLATURE:

LOCA	Loss of Coolant Accident
SI	Safety Injection
ATWS	Anticipated Transient Without Scram
PCS	Power Conversion System
LTDHR	Long Term Decay Heat Removal

INSIGHTS GAINED

In the course of performing PRA studies, those involved gain valuable engineering and safety insights. Some of the generally applicable insights gained from completed PRAs are discussed below, including conceptual insights and those related to overall risk, dominant accident sequences, system dependencies, human factors, and regulation.

Conceptual insights are the most important benefits obtained from PRAs, and the most general of these is the entirely new way of thinking about reactor safety in a logic structure that transcends normal design practices and regulatory processes. PRA thought processes introduce much-needed realism into safety evaluations, in contrast with deterministic thinking which, although it has served the nuclear power community well, often masks important matters due to its conservative, qualitative approach. PRA concepts can help improve understanding in many applications across a broad spectrum of activities including engineering, licensing and operations.

One of the first overall risk insights gained from WASH 1400, and confirmed by later studies, is that core melt is not a catastrophe in terms of public risk. This is due to the fact that the frequency of substantial offsite consequences from reactor accidents has been shown to be significantly less than the frequency of core melt. The importance of strong containments and reliable containment engineered safety features in limiting public risk from accidents has been highlighted and quantified. The basemat melt-through event ("China Syndrome") has been shown to be an unimportant contributor to public risk. Also, the logic structures involved in performing a PRA reveal the major contributors to core melt and to risk.

One of the early insights concerning dominant accident sequences was that large loss-of-coolant accidents do not dominate either core melt probabilities or public risk. With the completion of more PRAs, it is now clear that PWR accident sequences are dominated by small loss-of-coolant accidents and transients. For BWRs, the dominant accident sequence contributors by far are transient events, with loss-of-coolant sequences making only a minor contribution. In spite of these conclusions, which were available from WASH 1400 in 1975, only in recent years has regulatory attention begun to change from an obsession with large LOCAs to closer examination of small LOCAs and transients.

The dominant accident sequences for core melt are not always those that dominate risk, because different core melt sequences have different effects on containment failure modes. Also, different types of risk (e.g. early fatalities, latent fatalities) often have different dominant accident sequence contributors because early containment failures are usually associated with large estimates of prompt fatalities, whereas late containment failures can still cause latent effects.

Many insights on system dependencies have been provided by PRAs. One of these is the demonstrated importance of support systems, e.g. service water or DC power systems. Prior to the advent of the integrated systems approach used in PRAs, the safety significance of these support systems, in terms of their contributions to accident sequences, had not been quantified.

It has also been shown that complete independence of redundant trains of a system (i.e. no crossties) is not always a minimum-risk configuration. For some accident sequences, sequence termination and recovery would be enhanced if power sources or water sources could be made available to more than one train of a given system.

An important source of insights on system dependencies was a generic study of auxiliary feedwater (AFW) systems conducted by the U.S. NRC in 1979. (See Reference 24.) One of the findings of this study was that AFW systems that meet the same regulations can have very different reliabilities, varying by a factor of about 100. Also, undesirable AC power dependencies were found in some of the steam-driven AFW trains, e.g. lube oil cooling for steam-driven pumps.

The subject of human factors in reactor operations has also benefited from insights provided by PRAs. The combination of PRA studies and the Three Mile Island-2 accident has greatly increased the amount of attention given to human factors issues. Quantitative estimates, with large uncertainty ranges, of the contributions to core melt probability or risk from human actions can be derived from PRA results. Large uncertainties are associated with such estimates because of the lack of large data base on human behavior and because evaluation techniques in this area are in an early stage of development.

Ultimately, of course, virtually all reactor accidents are traceable to one or more human errors in design, fabrication, construction, maintenance or operations. In the narrower area of operations-related human factors, i.e. maintenance, testing, cognitive errors, manipulation of controls, etc., PRAs have shown that, in general, about half the public risk that might arise from reactor accidents can be related to such human errors. Stated another way, perfectly functioning structures and equipment would reduce a given risk estimate for a specified plant configuration by only about a factor of two. This PRA insight is one of the driving forces for the increased attention being given to human factors.

Insights related to regulatory activities have also been provided by PRAs. The disciplined logic structure of a PRA makes it possible to perform independent, comprehensive safety audits of nuclear power plants. (This was a consideration in the request by the U.S. NRC for PRA studies at several high-population sites.) This safety audit function is independent in that PRA techniques have not been widely used in the existing design and licensing practices in the U.S., and it can be comprehensive in the sense that essentially all contributors to public risk are subject to evaluation, unrestricted by regulatory considerations or design and operations practices.

PRA techniques make it possible to establish risk-based priorities in a number of regulatory applications, e.g. rulemaking, generic issues, research and development, and inspection and enforcement. PRAs are also needed to perform meaningful cost-benefit evaluations, which are becoming an important factor in regulatory activities in the U.S. Perhaps most important in the regulatory context, PRA techniques make possible the systematic evaluation of the fabric of existing regulations to make them more consistent and rational.

PRA APPLICATIONS

The most useful applications of PRA techniques are those that do not rely soley on "bottom line" estimates of public risk. This does not mean that quantification is unimportant, because PRA studies without quantification would lose nearly all of their capability to produce engineering and risk-related insights. At some point you have to believe the numbers, giving due consideration to their associated uncertainties. Quantification is essential, for example, in

- identifying and isolating important accident sequences from an array of tens of thousands of possible sequences,
- establishing risk-based priorities in many different contexts,
- performing risk or reliability evaluations of alternative designs or procedures
- contributing to meaningful cost-benefit evaluations.

INDUSTRY APPLICATIONS

A list of existing or possible industry applications of PRA techniques is given in Table 3. Because of space limitations, only a few of these applications will be discussed here. Most of the U. S. industry applications of PRA to date have been directed at resolving specific near-term problems, such as responding to questions or directives from the NRC.

One long-term application is in place, however, and that is a Continuing Risk Management Program (CRIMP) instituted by Consumers Power Company at its Big Rock Point plant. A group of four to six people are implementing the program, and these people are familiar with the logic models and other details of the PRA performed for the plant. The responsibilities of these individuals include updating the models to reflect the current as built plant configuration, collecting additional failure and maintenance data, performing trend analysis on data collected to detect changes in equipment availability as the plant ages, and performing evaluations of new safety issues as they arise.

Applications of the Zion PRA are focused on two items from Table 3, the technical audit of plant safety and assisting decisionmaking on possible design modifications. Specifically, the study analyzed the risk-reduction benefits of (1) using a core-catching ladle to retard the loss of containment integrity in core melt accidents, (2) adding a filtered vent to the containment to reduce the probability of gross containment failure from over-pressure, and (3) increasing the reliability of the containment spray system.

The overall conclusion of the Zion PRA is that the public risk is very low and therefore major design changes are not warranted based on risk considerations. The core ladle was found to produce an insignificant reduction in risk. The provision of a modified diesel-driven containment spray system or filtered vent yields a reduction of risk of about a factor of two. However, the containment spray modification provides a uniformly better risk reduction than the filtered vent, and the filtered vent would be very expensive.

REGULATORY APPLICATIONS

A list of existing or possible regulatory applications of PRA techniques is given in Table 4. Once again, because of space limitations, only a few of these applications will be discussed here.

A fundamental change in U.S. NRC policy concerning the first item in Table 4, providing assistance in the formulation of new regulatory requirements, occurred in October 1981 when the NRC established a Committee to Review Generic Requirements[25]. The memorandum from the NRC Chairman establishing this group states that the analytical tools to be used "would be expected to include cost-benefit analysis and probabilistic risk assessment where data for its proper use are adequate." The establishment of this committee, with PRA and cost-benefit analyses in its charter, has helped to focus new regulatory requirements on issues genuinely important to controlling public risk.

Another application of PRA techniques being pursued by the U.S. NRC and listed in Table 4 is dealing with generic safety issues. In November 1982 a draft report[26] was published concerning the establishment of priorities for generic safety issues. This report states, as part of the basic approach for assigning priorities, as follows:

> "A quantitative estimate is made of the safety importance of the issue, measured in terms of risk (product of accident probability and radiological consequences) attributable to the issue and the decrease in risk that may be attainable by resolving the issue."

TABLE 3

INDUSTRY APPLICATIONS OF PRA TECHNIQUES

- GENERAL
  - Sharpens focus on genuine risk issues
  - Makes apparent important risk contributors
- Basis for continuing risk management program
- Independent & comprehensive technical audit of safety
- Engineering: Safety insights, improved understanding of systems, plant support
- Operations: Training and plant support, e.g. simulators, procedures, technical specifications, maintenance and testing
- Interactions with the regulator
- Investment risk (loss prevention) evaluations
- Decisionmaking on design alternatives and operations practices
- Cost-benefit evaluations
- Systems interaction (dependency) analyses
- Reliability engineering - systems and components
- Evaluating the significance of operating events
- Evaluating specific issues as they arise

A planned future regulatory application of PRA techniques, also listed in Table 4, is the generic implementation of safety goals for nuclear power plants. One useful implementation method would be the systematic evaluation of regulations, making changes where appropriate, to provide assurance that a population of nuclear plants complying with the regulations will meet the established safety goals. A policy statement on safety goals[27], including an evaluation plan, has been published by the U.S. NRC. A two-year evaluation period is now in progress, and a decision on the regulatory use of safety goals in the U.S. is expected in 1985.

The routine use of PRA and safety goals in the licensing of individual reactors is of questionable value because the focus of this activity is on compliance with regulations. PRA and safety goals should be used instead in a broader regulatory context to refine regulations and regulatory practices to make them more consistent and rational.

Also, an Integrated Safety Assessment Program (ISAP) is in the planning stage at US NRC as of mid-1983. The concept is to replace the Systematic Evaluation Program (an evaluation of older plants against present requirements) and the National Reliability Evaluation Program (PRA studies for all plants). It will require that PRAs be done on essentially all U.S. LWRs at the rate of about six per year. The results of the PRAs will be used, along with all other available safety information, by the utilities to address all outstanding regulatory issues (unresolved safety issues, generic safety issues, TMI action plan items and plant specific issues) affecting the plant. The utility will be expected to recommend which issues need to be addressed, which need not be addressed, and to

TABLE 4

REGULATORY APPLICATIONS OF PRA TECHNIQUES

- ASSIST IN FORMULATION OF NEW REGULATORY REQUIREMENTS
- ASSESS EXISTING REGULATORY REQUIREMENTS
- DEAL WITH GENERIC SAFETY ISSUES
- IDENTIFY THE TOPOGRAPHY OF ACCIDENT SEQUENCES
- EVALUATE LICENSING, QUALITY ASSURANCE AND INSPECTION CRITERIA
- GUIDE REACTOR SAFETY RESEARCH
- ESTABLISH PRIORITIES FOR ALLOCATION OF REGULATORY RESOURCES
- EVALUATE NEW DESIGNS
- PROVIDE BASIS FOR EMERGENCY PLANNING REQUIREMENTS
- GENERIC IMPLEMENTATION OF SAFETY GOALS
- ADDRESS NEW SAFETY ISSUES AS THEY ARISE
- ADDRESS SPECIFIC ISSUES IN LICENSING REVIEWS

recommend a scheduled program (perhaps over a period of 5 years) for their accomplishment.

This approach is to be commended because it represents a good attempt to combine in a sensible way the insights from the normal deterministic regulatory process with the insights gained from PRAs to address outstanding safety issues. As these individual utility plans are reviewed and approved by the NRC, they will establish a body of practices for the generic resolution of most outstanding regulatory issues.

The NRC activities discussed above clearly indicate that PRA is coming into the mainstream of regulatory practices at the U.S. NRC.

CONCLUSIONS

Experience to date has clearly demonstrated that PRA techniques provide engineering and safety insights that are not attainable through any other means. These insights are the most valuable benefits derived from PRA studies, and are far more valuable than the quantitative estimates of public risk because we now know that the public risk from most reactor designs is very small. Insights attained from completed PRAs cover a broad range of issues of interest, including new concepts and thought processes, overall risk, dominant accident sequences, system dependencies, human factors and regulatory practices. PRA techniques have a wide spectrum of possible applications in the nuclear industry and in regulation. These methods can shed light on difficult technical problems as well as assist in regulatory decisionmaking.

Two commonly-heard criticisms of PRA are that "there isn't enough data" and that "the uncertainties are too large." Neither of these criticisms withstands scrutiny. If there were "enough data," the evaluations could be performed using statistical methods, and probabilistic techniques would not be required. More importantly, the presently-used data base, though not as complete as would be desired, has been shown to be capable of producing meaningful results, and forseeable improvements in data will probably produce only second-order effects. The real question is whether we are better off in our understanding of reactor safety with PRA insights or without them. In the U. S. it appears that PRA insights have come of age.

With regard to uncertainties, while they require the exercise of some caution in decisionmaking, the presence of large uncertainties is not unique to PRA. Virtually all design, regulatory and management decisions are made in the face of uncertainty. Further, many of the benefits of PRAs are not adversely affected by the presence of uncertainty.

PRA techniques do have some well-defined limitations. Some problems or issues are not amenable to evaluation by PRA methods, e.g. sabotage, diversion of nuclear materials, and detailed design of components. The presence of uncertainties must be considered in the application of results, and judgements made accordingly. Also, PRA techniques are not yet fully mature in many areas and new models are evolving continuously.

Because of PRA's unique capabilities, and with recognition of its limitations, these methods are rapidly entering the mainstream of industry and regulatory safety considerations. It can be said with some confidence that, at least in the U.S.A., PRA is here to stay.

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