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Planning for Rare Events: Nuclear Accident Preparedness and Management

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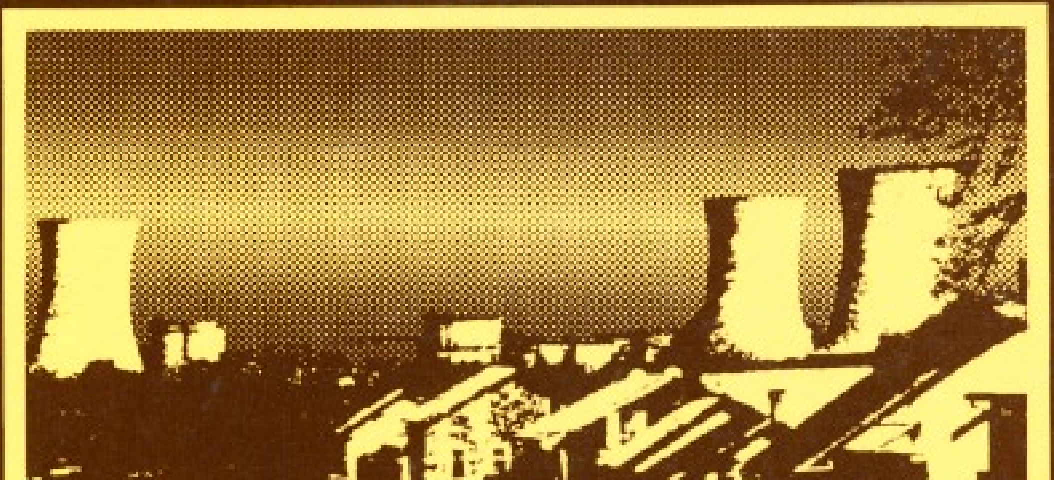

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Proceedings of an International Workshop
January 28–31, 1980
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IIASA PROCEEDINGS SERIES

Volume 14

Planning for Rare Events: Nuclear Accident Preparedness and Management

PLANNING FOR RARE EVENTS: NUCLEAR ACCIDENT PREPAREDNESS AND MANAGEMENT

Proceedings of an International Workshop
January 28–31, 1980

JOHN W. LATHROP

Editor

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The cover illustration was reproduced from a photograph of the cooling towers of Three Mile Island, as seen from Goldsboro, Pennsylvania.

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FOREWORD

This book summarizes the proceedings of a January 1980 workshop on "Procedural and Organizational Measures for Accident Management: Nuclear Reactors," sponsored by and convened at the International Institute for Applied Systems Analysis, Laxenburg, Austria. This workshop was part of an ongoing research program on risk management within IIASA's Management and Technology Area. While the work addresses general problems in risk management, it is our firm belief that the results are more apt to be useful if they are developed in the context of concrete, real-world case studies.

Consequently, our work began with a study of the management of technological disasters that focused on the responses to two blowouts on oil platforms in the North Sea (see David W. Fischer, editor, *Two Blowouts in the North Sea: Managing Technological Disaster*, Pergamon Press, 1981—another volume in this IIASA Proceedings Series). After examining problems in preparedness for and management of nuclear reactor accidents—the topic of this book—the program is now moving on to study the use of risk assessments in siting liquefied energy gas facilities.

As the title of the workshop indicates, the emphasis in this volume is on procedural and organizational issues in accident management. This focus was chosen because previous work on the North Sea oil blowouts and analyses of the accident at Three Mile Island indicated that, while the technical aspects of accident prevention had received much attention, nontechnical organizational aspects of the accident-response systems can be equally important. Yet these latter aspects have been the topic of much less study. It is our hope that this volume will take a modest step toward correcting this situation.

Alec Lee
Chairman
Management and Technology Area

ACKNOWLEDGMENTS

The editor would like to thank Rolfe Tomlinson, former Chairman of IIASA's Management and Technology Area, for his support and guidance during the process of preparing for the Workshop. Thanks are also due to Craig Sinclair, former Deputy Chairman of the Area, who was instrumental in organizing and conducting the Workshop. A special acknowledgment is reserved for David Fischer, who first thought of having the Workshop, created its research framework, and directed its initial planning stages.

I am also grateful to Vladimir Averkiev and Alexander Iastrebov for translating and editing the Russian papers, and to Gary Hamilton for preparing some of the discussion material. Finally, I would like to thank Paul Makin for guiding the production of the volume, Loretta Hervey for her remarkable job of editing, and Hilary Aziz for her professional composition of the manuscript.

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I. INTRODUCTION

1

OVERVIEW

John W. Lathrop
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BACKGROUND

The deployment of large-scale hazardous facilities, such as nuclear reactors or liquefied energy gas terminals, generates serious problems for emergency planning and preparedness. Foremost is the need to plan and prepare for accidents of high consequence but low probability. Because of the outstanding safety record of commercial nuclear power, nuclear accident management experience has been assembled slowly. Accident management planners must rely instead on drills and procedures that lack authentic testing. The difficulty is compounded by the inability to anticipate all the ways a complex system can founder and by the development of obstructive "mindsets" that are not validated by actual accident experience (see The President's Commission 1979).

The Reactor Safety Study (USNRC 1975) broke new ground in assessing the technical aspects of nuclear safety. With its various critiques (e.g., Kamins 1975, Lewis *et al.* 1978) the Reactor Safety Study represents the core literature in the field. But although these documents identify human error as an important component of overall risk, the organizational and procedural aspects of accident preparedness and management have not been given full attention. To redress this gap in nuclear risk research, the Management and Technology Area of the International Institute for Applied Systems Analysis (IIASA) convened a workshop in January 1980 to focus specifically on organizational and procedural aspects of nuclear reactor safety.

After the workshop had been scheduled, its aims were indirectly endorsed by the two major commission reports on the accident at Three Mile Island in the USA. The President's Commission on the Accident at Three Mile Island (1979) concluded that

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> To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organizations, procedures, and practices—and above all—in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry.

The Nuclear Regulatory Commission Special Inquiry Group (1980) put similar emphasis on organizational problems:

> The one theme that runs through the conclusions we have reached is that the principal deficiencies in commercial reactor safety today are not hardware problems, they are management problems.

Participants from 17 countries attended the IIASA workshop, representing operators, regulators, emergency management agencies, and local, regional, and national governments. While it would have been natural for the workshop to center its attention on TMI, this tendency was resisted by the organizers, for this would have involved the classic dangers of "planning for the last war." Instead, the workshop organizers encouraged the presentation and comparison of each country's current accident management plans and procedures.

No discussion of nuclear accident management plans should proceed very far without an acknowledgment of existing research on the topic. One of the best examples of such work is a document issued by the International Atomic Energy Agency, "Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities" (1979). In fact, four participants at the IIASA workshop were involved in the writing of that document. The IIASA workshop was not intended to supercede this work, but rather to supplement it with international experiences in the field. The papers delivered at the workshop and the accompanying discussions covered an extremely broad range of topics, going far beyond the various details of each country's plans. The topics included problems of maintaining preparedness for rare events, learning from past accidents, the role of the public in accident management, considerations of public attitudes, the desirability of candor in the planning process, and problems of liability.

Overriding the national differences in emergency plans was the fact that the USA had had a recent accident, while the other countries were fortunate enough to have only plans and exercises to talk about. While the representatives from the US were frank about their emergency plans—where they functioned and where they failed—the representatives from other countries could only discuss theoretically how their plans would work. It was difficult, then, to compare the US plans with the others. The US plans could be viewed with the benefit of post-accident hindsight, while the performance of other countries' plans could only be estimated. This difficulty highlights one of the central problems of planning for rare events: plans and preparedness must be maintained without authentic testing.

The Problem of Uncertainty

A comparison of the descriptions of the TMI accident with the descriptions of accident management plans contained in this volume illustrates the most general problem of planning for rare events. One discovers that not only were the technical aspects of the TMI accident unforeseen, but the very character of the accident was unanticipated by the accident management plans. The accident developed very slowly and was poorly understood—at any given moment in the first three days there was a great deal of uncertainty or misunderstanding as to the current and future status of the plant.

While it is dangerous to react too specifically to TMI (since the next accident will surely differ), the fact remains that a slow, confusing accident could recur and should be accounted for in accident management plans. Yet a review of the accident management plans shows that in many cases an implicit assumption is made that an accident will be marked by a well-understood initiating event, and that the potential dose to members of the public, or a relatively low bound on that dose over the next few hours, will be known. Several plans described in this volume discuss the appropriate ranges of dose within which particular population protection countermeasures should be taken. Yet how would such a dose range assist a decision maker faced with a hydrogen bubble that may or may not explode, as happened at TMI? Of course, later calculations showed that the bubble could not have exploded, but that is not relevant here. What matters is that during the accident a decision maker at TMI only knew that the bubble might explode and might lead to a release. Given that uncertainty he was not aided in his accident management decisions by a countermeasure guideline based on a dose range.

The narrow conclusion to be drawn from this example is that accident management plans should be designed to assist the people who must cope with a very uncertain plant status. But the example also has a much broader message: planning for rare events can be seriously hampered by basing plans on past events or hypothetical events, which in retrospect tend to be well understood. An accident situation may in fact be very poorly understood by the participants as it unfolds. That was certainly the case at TMI.

DEFINITIONS

The remainder of this introduction summarizes the elements and problems of nuclear accident preparedness and management, and then briefly describes the contents of the book. Naturally and appropriately, those aspects of the problems of accident management that fit into the focus of the workshop will be emphasized here, i.e., procedural and organizational measures.

Definition of a Nuclear Accident

A nuclear accident is defined in this volume as an occurrence at a nuclear reactor associated for some period of time with a significant probability of an immediate or future release of nuclear material. 'Significant probability' here means a probability high enough to require consideration of off-site countermeasures. The most important feature of accidents as they are defined here is that they are extremely rare. Most of the time design features and operator vigilance combine to prevent off-normal events from evolving into an accident. It is crucial to make a distinction between prevention and management here, for the workshop did not address preventive measures or instrumentation and operator procedures designed to deal with an off-normal event before it becomes an accident. Rather, this volume concentrates on how to proceed when accident prevention mechanisms fail.

The Elements of Nuclear Accident Management

While the basic elements of nuclear accident management are quite straightforward, they can generate difficult decision-making tasks. A central decision in nuclear accident management as discussed here concerns which population protection countermeasures to execute, if any. Three types of countermeasures are of interest:

- shelter (i.e., advising the population to stay indoors);
- prophylactic medicine (administering potassium iodide or other medicines designed to prevent radioiodine take-up by the thyroid);
- evacuation (advising the population to leave the area).

Each of these countermeasures can specify a target population (for instance pregnant women) and the area of application (sector, radius). On a longer time scale other countermeasures may be taken, such as control of possibly contaminated food products, but these steps typically do not involve decision making under time pressure and uncertainty—the main focus of this volume.

The basic elements of nuclear accident management may be briefly listed as follows:

(1) *Identification of accident and initiation of technical control measures.* A nuclear accident does not always start in a clearly recognizable way. The realization that an accident is taking place may involve detection of a set of plant parameter values that must be subtly discerned within the noise of normal or off-normal but non-accident fluctuations. A more extensive discussion of this phenomenon is given in a study by Bull *et al.* (1980) of nuclear accident management.

(2) *Assessment of accident severity.* It may be difficult to assess accident severity when a reactor is behaving in an unanticipated way. It involves determining what is happening

and is going to happen in terms of radioactive releases to the atmosphere. When a full understanding of the system cannot be attained, the likelihood of a release or of various magnitudes of releases must be roughly estimated.

(3) *Communication to government authorities.* The assessment of accident severity must be communicated to authorities clearly enough to permit sound accident management decision making. This step transfers the focus of accident management from on-site to off-site actors, and adds the element of political choice to the previously technical decision making process.

(4) *Deciding which countermeasures to execute and where.* This step calls for weighing the costs and risks of various countermeasures (including taking no countermeasures).

(5) *Execution of countermeasures.* While this step may seem central to accident management, it is not highly problematic from a decision-making point of view, and so receives little attention in this volume.

After control of an impaired reactor is fully regained, three more accident management steps should be taken. They belong to the gray area between accident management and preparedness for the next accident.

(6) *Resumption of normalcy.* This step includes reversing evacuations, settling liability claims, and long-term cleanup.

(7) *Analysis of the accident for lessons to be learned.* In the case of TMI, extensive post-accident analysis has been carried out. In fact, the IIASA workshop reported on in these Proceedings may be considered part of that process.

(8) *Incorporating lessons learned into accident management plans.* This feedback process does involve some hazards. For instance, accident management plans may be altered too specifically in response to the detailed characteristics of a past accident, so that overall preparedness for the range of possible future accidents is impaired. As well, a past accident may in hindsight be analyzed only as a well-understood event; thus plans may not be modified to deal with a future accident, which in fact could be poorly understood by participants as it progresses.

Central Problems of Nuclear Accident Management

Although any accident situation presents a possibility of radiation exposure to the population, uncertain plant status, meteorological conditions, and other factors typically make it impossible for anyone in the midst of an accident to know or predict with any certainty the size of the population dose. The decision to take countermeasures is further complicated by the risks associated with them. These can include loss of life in the case of an evacuation, and rare negative side effects in the case of administration of potassium iodide. There are also political and financial costs associated with executing countermeasures. Even the dissemination of information concerning an accident and the consideration of countermeasures can have negative effects on the population. The Kemeny Commission concluded that mental distress was the most serious health effect of TMI (The President's Commission 1979). Thus accident management decision makers must balance the risks of uncertain radiation exposure in the absence of countermeasures with the uncertain costs and risks of implementing countermeasures that will reduce, but not eliminate the risk of exposure. The Kemeny Commission suggests that accident managers should consider, in addition, the effects of indecision on the public.

The balancing of costs and risks between implementing and not implementing a countermeasure is complicated by the inability of a single person to have a full appreciation of all the costs and risks. People with technical backgrounds and familiarity with the impaired reactor are needed to assess plant status and estimate the likelihood of a radiological release. People with legitimate governmental authority are needed to make the difficult trade-offs between the costs and benefits of various countermeasures, to order their execution, and accept responsibility for the consequences. Yet technical personnel typically do not have legal authority, and government officials cannot be expected to possess technical expertise and familiarity with the plant. In short, the competence necessary to make responsible accident management decisions rests with two groups of people.

Clearly, good communications between these two groups is essential. Even when an accident is well understood such communication is difficult between groups of people with different perspectives. When an accident is poorly understood, as was the case during the first days at TMI, it becomes even more challenging to convey the state of knowledge about the situation to government authorities in such a way as to permit sound accident management decisions. An accident management system must be designed to aid these communications and decision-making tasks as much as possible.

Preparedness

In this context the concept of nuclear accident preparedness has three main elements:

— development and maintenance of accident management plans, including emergency procedures and the organizational framework within which the plan is to be executed;
— maintenance of staff and equipment in place; and
— maintenance of the readiness of that staff and equipment.

At first glance, maintaining preparedness seems more straightforward than accident management. However, two basic characteristics of nuclear accidents make preparedness just as challenging as accident management: they are very rare and they are potentially extremely costly in terms of lives and property.

These properties lead to four central problems in maintaining preparedness:

(1) Most preparedness and management activities concentrate on preparedness. The rarity of nuclear accidents means that the people and organizations involved in accident management spend year after year maintaining preparedness, never experiencing an accident. This contrasts with the activities of general emergency management agencies, which may deal with several flood and transport accident evacuations each year. Of course, such general emergency agencies may be part of the nuclear accident management system, but only part. In most respects this system is not authentically exercised. As Oran Henderson (Director of the general emergency management agency that was involved in the TMI accident) points out in Chapter 5, there are important differences between normal evacuations and evacuations associated with nuclear accidents.

(2) The difficulty of nuclear accident management decisions suggest that they should be pre-analyzed as much as possible in the planning process. Since accident management involves decision making under extreme uncertainty, with knowledge and authority divided between technicians and government officials, each key person involved in an accident may be burdened with an extremely difficult information-processing and/or decision-making load. Considering the large costs associated with inappropriate decisions, it is worthwhile to invest heavily in plans that anticipate and resolve as many communications and decision problems as possible, and thus decrease the burden of decision making in the midst of a stressful accident.

(3) The extreme rarity of nuclear accidents means that any single action that consumes resources to increase preparedness is almost certain to fail to reap direct benefits. This may have a negative effect on the motivation of people involved in nuclear accident preparedness and may be expressed in behavior ranging from organizations' budgetary decisions to individuals' job planning decisions. Thus any effort to maintain preparedness must involve special rewards and incentives to ensure that individual decisions are made in the best interests of society.

(4) It is difficult to effectively test a nuclear accident management system. Given the lack of actual accident experience, drills and exercises must be used to assess preparedness. Of course, during a real accident the possibility of catastrophic consequences puts very high stress on decision makers—stress that may greatly affect individual performance. It is extremely difficult to generate such stress in a drill or exercise. It is also difficult for an exercise to simulate the degree of uncertainty and confusion that may accompany a real nuclear accident.

OUTLINE OF CONTENTS

The second chapter in this Proceedings, "An Open Discussion of Problems in Accident Preparedness and Management," presents the main points raised in the discussion sessions of the workshop. In the spontaneity of the discussions, workshop participants openly addressed the unresolved problems of accident management. The remainder of the volume is devoted to the participants' formal presentations. These have been grouped into four sections.

The Accident at Three Mile Island: Three Perspectives. In Section II three key people who had been involved in TMI describe the accident from their own viewpoints: Herman Dieckamp, President of General Public Utilities Corporation (GPU) (the parent company of the utility that operates TMI); Robert Vollmer, Director of the Three Mile Island Support Staff at the US Nuclear Regulatory Commission (NRC); and Oran Henderson, then Director of the Pennsylvania Emergency Management Agency (PEMA). Each describes the organizational framework within which his agency operated, and identifies needs, problems, and lessons learned from the TMI experience.

Emergency Planning and Preparedness: International Perspectives. In Section III representatives from six countries describe the nuclear accident management organizations in their home countries. The two US contributors both represent the NRC: Martin describes the interface between accident prevention and management, the division of responsibility between the operator and regulator, and lessons learned at TMI regarding organizational response; Collins explains accident assessment systems and compares bases for emergency planning (for instance, various zone concepts).

Matthews and Pepper of the Central Electricity Generating Board in the UK present a comprehensive description of UK emergency plans, organization, zones, and exercises. Clarke and Webb of the National Radiological Protection Board in the UK present the principles of UK dose criteria for countermeasures and the criteria themselves. Representing the Federal Republic of Germany (FRG), Bernhardt (Gemeinschaftskernkraftwerk Neckar GmbH) describes the on-site organization necessary to interface with off-site agencies, and principles of organization and authority. Von Gadow (FRG Ministry of the Interior) explains the division of responsibility among accident management agencies, dose criteria for countermeasures, and lessons learned in the FRG from TMI and domestic exercises. Kaspar (Ministry of Labor, Health, and Social Welfare) concentrates on an elaborate emergency management exercise performed in the FRG.

The paper by Baas and Bošnjaković (Netherlands Ministry of Health and Environmental Protection) presents the Dutch off-site accident management organization, the accident classifications and dose reference levels used in his country, as well as the Dutch review of the TMI accident. The paper by Beskrestnov and Kozlov of the USSR Ministry of Energy covers information management, accident classifications, and dose criteria for countermeasures. Finally, the paper by Teste du Bailler, of Electricite de France, briefly presents the French philosophy of nuclear accident management.

Broader Issues. Section IV addresses broader historical, legal, and behavioral aspects of nuclear power. Here Harold Green (George Washington University National Law Center) briefly reviews the history of the nuclear industry and public attitudes in the US, discusses the effects of TMI on the credibility of the US nuclear industry, and closes with a discussion of the importance of candor and its role in accident preparedness and public acceptance of nuclear power. The paper by Harry Otway and Rolf Misenta (Joint Research Center, Ispra) discusses the job demands of a nuclear reactor operator, the underlying variables that determine his performance, solutions to the problem of maintaining operator vigilance, and possible future roles of the operator. Gary Hamilton (Lyndon B. Johnson School of Public Affairs) then describes the liability, compensation, and cost aspects of nuclear accident management in the USA.

Technical Considerations. In the final section of the book, representatives of five countries discuss technical aspects of nuclear accident management. The paper by Ibragimov (USSR Ministry of Energy) presents three different taxonomies of nuclear power plant equipment and operations, then considers various bases for safety and reliability requirements. Kumamoto *et al.* (Kyoto University) describe a data storage and retrieval system designed to help operators, emergency planners, risk assessors, and plant designers to learn from previous accidents. Deme *et al.* (Hungarian Central Research Institute) describe an off-site quick dosimetry system and its possible use in decision making about countermeasures. Danzmann (Gesellschaft für Reaktorsicherheit, Köln) describes a risk assessment of reactor accidents, taking accident management countermeasures into account in the calculations of doses received. Finally, Brinckmann (Central Institute for Nuclear Research, German Democratic Republic) discusses the possibilities of using noise analysis for early accident management.

CONCLUSION

This overview has introduced the central concepts, definitions, and problems of nuclear accident preparedness and management, as well as a brief preview of the papers. It is intended to orient the reader to the scope of the workshop upon which this volume is based. The following chapter contains a synthesis of the themes that arose in the workshop discussions. The remainder of the book is devoted to the papers presented by the workshop participants.

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2

AN OPEN DISCUSSION OF PROBLEMS IN NUCLEAR ACCIDENT PREPAREDNESS

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This chapter is structured around major themes that emerged from workshop discussions. It is in no way meant to replace or summarize the 21 papers presented in the following chapters of this volume; in fact, none of the themes presented here is fully addressed in any one paper. Rather, this chapter puts the main points of the discussions and findings derived from the discussions into readable form and, hopefully, will entice the reader to look further into the volume for more detailed treatments of nuclear accident preparedness and management issues.

As may be expected, discussions at the workshop, often involving issues as broad as the acceptability of nuclear power, gave rise to markedly different points of view. As a result, it is extremely difficult to appear to be "fair" in representing the workshop discussions. The participants represented such diverse points of view that some of them will take exception to any point presented here. Many participants were part of the nuclear industry, emergency management agencies, or regulatory bodies, and so quite naturally felt that nuclear accident preparedness and management is currently being effectively performed. In contrast, this chapter emphasizes *problems* of nuclear accident preparedness and management. This should not imply that the problems are dominant or unsolvable. The problem orientation adopted here is simply meant to reflect the tone of the discussions and to serve as a constructive contrast to the often positive tone of the papers.

In the course of the discussions, given topics were often addressed several times. Thus, my task as editor was to organize comments on discussion topics (where appropriate, quotes or paraphrases) into a cohesive sequence. Although I tried to remain as neutral as possible, I could not make the synthesis without some interpretation. For this reason, it must be stressed that the points presented here are my responsibility rather than that of the workshop participants.

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Theme 1: There is no room for complacency in nuclear accident preparedness and management.

On the last day of the workshop, John Horan of the International Atomic Energy Agency (IAEA) reminded the participants that they were not addressing an academic, hypothetical problem:

> I would like to spend a minute or two on the topic of complacency. A number of times during the workshop, comments have been qualified by the phrase, "*if* there is another nuclear accident." I feel that our approach has to be to use the phrase "*when* the next accident occurs." I have identified six major accidents in the past 27 years of our industry. Only two involved commercial nuclear power plants: Browns Ferry and, of course, Three Mile Island. One can detect something of a periodicity in the occurrence of accidents—about one every five years. But I don't think that our past history is that much of a light to guide us; today we have many more power plants coming on stream and much higher power levels. In addition, many of our plants are now aging. As Mr. Pepper noted, the employees operating the plants are also aging. For these reasons there is no room for complacency.

Perhaps those least apt to be complacent are the political authorities who may be forced to make difficult nuclear accident management decisions. As discussed in the introductory chapter, a basic problem in accident management is the frequent need for authorities to make decisions on population protection countermeasures on the basis of incomplete technical accident assessments. This decision problem can be partially characterized in analytic terms, but the human dimension must not be underestimated. The question of decision making under uncertainty came alive in comments made by workshop participants who knew they could find themselves in this situation at some time in the future. One participant commented that he could not imagine making such decisions—it seemed to him like a situation out of Alduous Huxley's *Brave New World*. In this context Godfried van den Heuvel, Mayor of Borsele, Netherlands (a town situated near the country's largest nuclear plant) spelled out what it might be like for him if there were an accident in the nearby nuclear plant:

> When something happens in the plant in Borsele, we have an excellent emergency plan to alarm and to help the people living in the surrounding area. In the event of an accident the operator informs his director and then the director warns me; he explains—as far as he knows—what happened in the plant and describes for me the size of the accident. If the accident is large an emergency committee will be called together, consisting of local authorities, technical experts, and officials from the national government, with the provincial governor as chairman. But in the period of time between

> the first message from the director of the nuclear power plant and the convening of the committee—two or three hours—I am responsible for managing the off-site response to the accident.
>
> The chance that immediate action would be necessary during that period seems very small. But if action has to be taken, then it would be very difficult for me to decide what to do at such a moment. I understand that evacuation involves a lot of risks for people, especially when it covers a large area. But as the figures discussed yesterday showed, failure to evacuate also involves a big risk. My problem is that I would have to look at different plans and alternatives, and then make a decision without sufficient guidance from specialists. My decision whether or not to order an immediate evacuation would be based only on a very small amount of information from the director of the plant. That is a great responsibility. You can only know after the event if your decision was correct or not.

Theme 2: Nuclear accident preparedness and management must account for the extreme uncertainty that may be encountered in the course of an accident.

2a: Three Mile Island exposed a basically unanticipated type of accident, one that developed slowly and in a confusing manner.

As Herman Dieckamp (General Public Utilities, Inc.) points out in his paper, one of the most significant aspects of the accident at TMI was the very slowly evolving stock of information regarding the actual state of the plant. This led to long periods of time when decision makers did not know whether radioactive substances were about to be released and instead had only an unexpressed probability distribution over possible events. This kind of accident was not adequately anticipated by existing specific countermeasure guidelines. This finding is troublesome for two reasons. First, nuclear accident management plans must be revised to handle such cases more adequately, but it is not clear how the revision should be implemented, or how its success can be evaluated. Second, the TMI experience suggests that sometimes the only way to expose a weakness in a safety system is to have an accident. If it took TMI to uncover one dramatic, unanticipated accident, how many other such accidents are possible in this technology, and are there ways to prepare for them? As Dieckamp commented during a discussion:

> In my mind the real reason that Three Mile Island occurred was not so much tied to deficiencies in procedures, training, or instruments, but rather to the fact that the system behaved in a way that was not generally anticipated. The operators had certain pre-

> conceived opinions about system behavior during a loss-of-coolant accident and about the kinds of diagnostic signals such an accident would trigger. The system did not behave as expected because of the peculiar position of the loss-of-coolant point. As a result the operators failed to diagnose the condition and reacted inappropriately. In fact their training and procedures probably inhibited them from doing the right thing. This realization leads to several questions. First, is our elaboration of system behavior complete enough to be used as the foundation for procedures and training? Second, since it may be unreasonable to expect that we can fully define systems in advance, does it not follow that we need operators with more than just procedural training on site at all times—operators with the fundamental knowledge and insight to diagnose unanticipated conditions and to take the right action?
>
> The accident spurred much discussion about the importance of simulators and simulator training. Many people think of simulators as control room mock-ups or replicas with all the instruments and switches in the right place. In my own mind the problem is not so much one of hand-eye coordination—knowing what switch to hit at which moment. Rather, the critical factor is the operator's insight into system response: as things begin to change, he should be able to immediately deduce what is happening. What are required are system simulations that can take into account most of the possible combinations and permutations of events; in effect the operators should be able to play with the simulations over a period of time to develop an inherent feel, an inherent understanding of system behavior.

In this context Robert Martin explained the unanticipated nature of the TMI accident from the Nuclear Regulatory Commission (NRC) perspective:

> Until TMI we had presumed that existing design work had given us a fairly good handle on the set of major accidents that could occur at a plant. Our presumption was that accidents progress rapidly, not over a protracted period of time, and soon bring the plant to some stable (albeit not favorable) state. Therefore our accident response was geared much more toward determining the magnitude of the radiological problem, the stable point the plant had reached, rather than dealing on a real-time, hour-by-hour basis with an evolving accident scenario. I don't think anybody's emergency planning has really been based on the *evolution* of an accident. Even within the utilities, corporate engineering structures were not tied in to provide engineering evaluation on a real-time basis. The existing plans called for emergency staff, trained to rapidly respond to a set of preplanned or anticipated conditions, to establish a stable state in the reactor and

> then to evaluate the radiological consequences of the accident. In my view, everything at TMI was geared towards that kind of a response. There was no heavy engineering involvement in the first several hours of the accident, with the General Public Utilities corporate engineering headquarters, with the licensee, with Babcock & Wilcox, or with anyone else. Rather, the small, on-site emergency team functioned as it was designed to function, that is, it dealt with the accident as best it could with available resources. Nobody anticipated that there would be a protracted period before any semblence of stability was established.

2b: In a poorly understood accident, such as the one at TMI, the unanticipated nature of the accident and the uncertainty pervading the first hours are critical factors.

As Dieckamp noted, the unanticipated nature of the TMI accident had a pronounced effect on the attitudes of accident management decision makers:

> One of the things that certainly strikes me is that this accident involved a sequence of events and net impacts on the plant that none of us had ever considered credible or possible. When that happens, one's degree of confidence and willingness to render a tough judgment about what is or is not credible is suddenly significantly changed. And one also becomes extremely aware of the remaining uncertainties and contingencies that may need to be dealt with. From my own point of view, I felt very strongly that we should throw every possible thought and every possible solution or anticipation into the pot for consideration.

Dieckamp explained that the uncertainty pervading the TMI accident situation did more than just compound the difficulty of regaining control of the reactor and of determining appropriate countermeasures:

> The question of determining the severity of the accident was indeed difficult. I think it contributed to the lack of understanding and the anxiety among the general public. God forbid that such an accident happen again, but if it should, I'd like to be able to be better informed about what is going on and for what reasons, so we can better communicate the situation to the public.

Perhaps the most important effect of the uncertainty was confusion and continually changing information about plant status. This situation led to several conflicting reports to the local government and media. The conflicts in these reports contributed to a loss of the credibility of the utility, which in turn caused the NRC to play a very different and much larger role than had ever been anticipated. Thus the uncertainty led to a rearrangement of the roles of the various agencies that was not part of accident management plans. Many people and agencies found themselves in roles that they were not prepared to play.

> *2c: In particular, the uncertainty and unanticipated character of a poorly understood accident may markedly increase the importance and difficulty of communications.*

In a poorly understood accident situation, summary descriptors of the accident or plant status are not available. This can lead to severe difficulties in communication, as several reports on Three Mile Island attest. For example, the Rogovin Report (1980) stated,

> ...[T]he inability of the utility's management to comprehend the severity of the accident and communicate it to the NRC and the public was a serious failure of the company's management.... Moreover, NRC and B&W [Babcock & Wilcox] employees in the control room also did not recognize or communicate critical information. And their offsite organizations did no better, and perhaps worse, than the utility's offsite engineers at GPU in New Jersey in demanding reporting of important information and in recognizing the significance of the information that they did receive. The...NRC and B&W did no better than [Metropolitan Edison/General Public Utilities] in reporting critical information up the management chain and acting upon it....

During the workshop Herman Dieckamp addressed the same problem in a more operational way; he described good communications as a basic requirement for making the best use of available personnel:

> The problem is to make the most effective use of one's technical resources. This requires that one plan ahead of time how to communicate the critical parameters and information in a preplanned and logical way to people off-site. One must aim to quickly give those people the best possible understanding of what is happening, so that they can begin to go to work in an effective, productive way.
>
> During the early days of the accident, the effectiveness of advisory and support people off-site was limited by the degree to which in-plant operations were efficiently communicated to them. This hindered their ability to determine the right questions and answers to worry about.

Later in the discussion, Dieckamp pointed out that due to the unanticipated nature of the accident, failures in communication occurred even when adequate levels of information were available.

> We did not think ahead of time in terms of establishing a correlation between plant operations and associated radiological releases. We were not able to give the authorities advanced warning as effectively as we should have, based upon known plant operations. We should have been able to say, "We are about to open this valve, we are about to make this gas transfer, this liquid transfer,..., we should expect a radiation release for 30 minutes, but only a limited amount because the tank involved has finite quantity, etc."

2d: There is a need for emergency plans designed to handle a slowly developing, confusing accident.

As discussed above, the lack of summary descriptors of plant status in a poorly understood accident situation can lead to communications problems. More generally, the lack of summary descriptors can put a much higher information-processing load on those involved in such an event than in the case of a well-understood accident. It follows that emergency management plans should be designed to help participants cope with and communicate about very uncertain situations. Each person involved in accident management must have a clearly defined role within a well-understood information-processing structure. To the degree possible, difficult but anticipatable decisions should be predecided in the planning phase. Dieckamp responded with the following statement when asked about the confusion that surrounded TMI:

> You are right when you say "confusion." There was a lot of confusion. That experience suggests that one should plan an organizational structure responsive to the need for expertise and specialization. A method is required for coordinating people with different specialties, people who should be assigned ahead of time. If such an organization is put into place early, on the first or second day of the accident, instead of on day four, five, or six, it can greatly alleviate the problem of confusion.

At another point in the discussion, Robert Martin explained the role plans should fill in managing the uncertainty of a nuclear accident. In his view, plans enable large numbers of experts to predecide critical decisions for the small number of people who must make those decisions in the stress of an accident.

> At some point during an emergency some information or a given circumstance will require that I make a deci-

> sion. As an operations-oriented individual, an emergency plan is to me a guide for making decisions. In general for organizations involved in implementing emergency plans, the plan is a vehicle for making decisions. But the decisions are not the same thing as the plans. A very small number of people make the decisions. A large number of people contribute to plans.

Drawing on his experience at TMI, Dieckamp identified a particular central role for emergency plans in nuclear accident management:

> It would have been nice if we had been smart enough at the time of the accident—or if we were smart enough now—to know how to immediately meld the owner/operator group and the NRC into one working team. A faster coalescence of both the operator and the regulator is needed to bring to bear the experience of both groups and to generate one list of questions and a common set of priorities.

2e: In particular, emergency plans must be designed to aid accident managers in making decisions on the basis of the information that is actually apt to be available in the course of an accident, i.e., very incomplete information.

It is one task to develop an accident management plan that calls for decisions to be made on the basis of all information that should, ideally, be available. It is quite another task to develop a plan that is resilient to confusion, that takes into account the likelihood that any accident will be accompanied by a certain amount of chaos and unplanned gaps in information. There can be a large difference between the information available in the midst of an accident and the actual state of affairs. Robert Martin made this clear in his description of the TMI case:

> We at the NRC have concluded that if we had had some other data, we might have been able to make better decisions at TMI. On the basis of the guidelines that Mr. Clarke presented in his paper, TMI was a non-event. But it was certainly not a non-event when decisions had to be reached in the course of the accident. At that time it was very much an event and an emergency. Analyses conducted after the accident showed radiation exposure to any individual was only 1% of the level below which no measures need be taken, according to the guidelines cited by Mr. Clarke. Those guidelines suggest that you would not even have to tell anybody about the accident—*if* you had known that that was going to be the outcome. But you did not know.

TMI is not the only example of a nuclear accident situation characterized by a lack of complete information on which to base decisions. John Horan described the period following the Stationary Low Power Plant 1 (SL-1) nuclear accident of 1961 in the following terms:

> ...during this time the major questions centered around the condition of the plant. Is it still critical? Is the coolant bubbling away? Are there potentials for components to readjust themselves, for another criticality to occur...?

In Horan's opinion all accidents are characterized by some degree of chaos:

> Much attention has been given to the chaotic condition that existed at Three Mile Island. But I don't really think this is unique. Even an automobile accident generates confusion. The larger the scope of an emergency, the higher is the likelihood of a chaotic situation. I think this is an inherent part of serious accidents in general.

But even when an accident situation is not chaotic, decisions may still have to be made on the basis of indirect and incomplete information. In the drill described by Dieter Kaspar (see Chapter 12), a recommendation for evacuation was made on the basis of the reported deteriorating state of the reactor (increasing temperature and pressure), rather than on information directly related to the release of radioactivity. This is an excellent example of accident management based on anticipations of future events— events that may be uncertain even given extensive information on the current state of the reactor.

One solution to the problem of insufficient information may be to limit the decision-making tasks of any one individual to those for which he is apt to have adequate and timely data, with a clear fall-back response proposed for the case when adequate data is not available. Harold Collins (NRC) gave one example of such a solution when he pointed out that accident management plans should include the use of plant instrumentation to recommend initial protective measures off-site, with a specific mechanism to handle situations in which the operator is confused. This idea is contained in the NRC's Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants (USNRC 1980). In Collins' words,

> The intent of the NRC document is to require that the nuclear facility operator make judgments *in his control room* about accident projection off-site. In other words, the operator should rely on his plant instrumentation to initially recommend protective measures off-site, rather than send people out into the field to make radiological assessments, a time-consuming activity. His decision to call off-site authorities and to recommend protective measures should be based initially on what he is seeing in the plant. If the operator cannot

> determine what is happening in the plant within about fifteen minutes, then he must notify the off-site emergency management authorities, according to the NRC document. He has to say, "I have the following problem of such-and-such proportions," or, "I have a problem, but I don't know how serious it is. You had better put your emergency organizations on an alert status."

The lack of complete information on which to base decisions may also be due to factors other than a poorly understood accident situation. For example, accident management may call for the implementation of technical procedures that have never been tried before. When asked for an example of such a procedure, Robert Martin discussed the hydrogen bubble at TMI:

> Consider the procedure by which the hydrogen bubble was removed from the primary coolant system. That was an evolution that was never predicated anywhere in the plant design or plant evaluations. The manner in which the hydrogen gas was dissolved and moved to a different part of the reactor coolant system for venting required increasing and decreasing the pressure and temperature in an involved process. There was no standard operating procedure for that evolution.

The problem of decision making on the basis of incomplete information may be compounded by other pressures. Oran Henderson (Pennsylvania Emergency Management Agency) brought up the question of political considerations:

> I think that the information that our Governor had at that particular time probably did not warrant either an in-place shelter or an evacuation of pregnant women and preschool-aged children. However, with the great number of outside pronouncements being made, the Governor was subjected to some political pressures. In addition, he couldn't get answers to all of his questions. In Washington there was debate among the members of the NRC as to what action should be taken. I think that the Governor was justified in what he did, but he could have made either decision [to order or not to order a limited evacuation] with the information that was available.

Theme 3: Some aspects of accident management plans presented at the workshop were not oriented toward handling the extreme uncertainty that may be associated with a nuclear accident.

As discussed in the introductory chapter, one typical framework adopted for accident management plans involves setting bounds on measured, anticipated, or projected individual radiation doses that could be caused by an accident. These bounds are to be used as at least partial guidance for recommending countermeasures.

A review of the Clarke, von Gadow, and Beskrestnov papers in this volume reveals three examples of such dose-based countermeasure guidelines. A fourth set of guidelines can be found in the US Environmental Protection Agency's Protective Action Guides (1975), which, for example, call for mandatory evacuation if the whole body dose exceeds 5 rem (anticipated maximum individual dose). Five of the six countries whose accident management plans were discussed at the workshop (FRG, Netherlands, UK, USA, USSR) had one form or another of dose-based countermeasure guidelines. As Clarke points out in his paper, each guideline represents a balancing of radiation risks versus the risks of the countermeasures.

But it is not clear how such guidelines would help in an accident involving a great deal of uncertainty about the status of the reactor. For example, how would such a guideline apply when the decision maker only knows that there is a 10% chance that the guideline will be exceeded in the near future? More concretely, we could ask, How would such a guideline have helped a decision maker at TMI late on March 30, 1979? He knew only that there was a hydrogen bubble in the reactor vessel, that its flammability was still being calculated/argued, that it could have exploded, and that this could have led in turn to major releases of radiation. Does the anticipated maximum individual dose apply to this uncertain situation? Not explicitly, though some probability distribution over such a dose is implied. At a later time it became clear that the hydrogen bubble could not have exploded, but the decision maker could not have known that on March 30th. How was he supposed to use the 5 rem guideline when faced with such uncertainty? Clearly, accident management guidelines should be linked more directly to information that the decision maker is actually apt to have available at the time the decision must be made.

This point was clearly made by Ernst Hampe (Commission of the European Communities), in response to a paper that presented dose-based countermeasure guidelines:

> Risk categories I, II, and III, representing dose ranges of 5 to 15 rads, etc. have been described here. What importance should we attach to these categories? I must frankly say that I am tempted to smile when such guidelines are presented, and I try to relate them to incidents or accidents that have occurred in various parts of the world. During the first two days of such events one doesn't have a clear picture of real consequences or how the situation may evolve. A nuclear accident differs from a railroad accident, a case in which one can immediately see what has happened or what can still happen. Moreover it is not unknown for effluent monitors to fail soon after the onset of a nuclear accident. In this light, does it make any sense to create such guidelines? Or would it be better to avoid such fine distinctions and simply issue warnings sufficiently in advance, say at the first sign of trouble or at least when a situation arises that is not fully understood?

Later in the workshop Herman Dieckamp presented a similar argument:

> I must say that the various definitions of categories of 5 rems, 10 rems, or 15 rems are very narrowly defined in relation to the levels of uncertainty that one may expect. The uncertainty in predicting the magnitude of a release is large, compared to the narrow differentiations of categories of accidents or incidents. My impression is that in an accident entailing radiological releases there is confusion and uncertainty; nicely drawn diagrams of communications channels become confused and short-circuited, and all of a sudden one loses the ability for rational decision making. We should not think in terms of neat little relationships in which we plot a parameter and when it reaches a certain trigger level "we do something." Rather, there will probably be emotionalism and uncertainty; anxiety will take control, rather than careful technical assessments.

Dieckamp also pointed out a related problem associated with countermeasure guidelines based on off-site doses. Such guidelines tie decision guidance to meteorological conditions, and this may add a great deal of uncertainty to the overall situation. As Dieckamp said,

> During the TMI accident the question of off-site impacts became a very difficult and uncertain issue. It is not so cut-and-dried for radiological teams to go out with instruments and measure here and there. The accident at Three Mile Island occurred in a time period of three or four days with the worst possible meteorological conditions that one can imagine—absolutely dead, still air. A puff of radiation meandered about in these conditions. This contributed to the confusion about the relationship of radiation releases to the plant and the accident. It didn't seem to make sense.

John Horan related meteorological conditions to the broader problem of misinformation.

> Mention has already been made about the problem of misinformation and the lack of data needed to inform local authorities. During one event in which I was involved a number of years ago, I was given a wind direction that was off by 90°. And this information came from one of the best meteorological research organizations available in the United States. Under the stress of the emergency, this misinformation was delivered and we operated under it for six hours. This was a mistake on our part as well, because we should have verified the wind direction ourselves. I feel the potential for operating under misinformation will always exist.

In addition to the problems associated with the use of off-site doses as a guideline for countermeasure decisions, there are other aspects of accident management plans that do not address the extreme general uncertainty that may be associated with a nuclear accident. Consider, for example, the criteria for simply recognizing that an accident is taking place. As Herman Dieckamp said,

> How does one know when to sound the alert? In the case of TMI, most of the alert criteria were based upon the so-called design basis accident—a major LOCA [loss of coolant accident]. We had a list of about eight parameters, all of which related to the characteristics of a LOCA. For instance, one such parameter was high containment building pressure. We never did have high containment building pressure during the TMI accident. Containment was to be isolated at four pounds per square inch [overpressure], again based upon a major LOCA. It took about four hours before the building pressure ever went high enough to initiate that isolation; in fact even then the isolation system initiated somewhat early, while the pressure was still well below four pounds.
>
> The first declaration of emergency that called for off-site notifications—what we call a site emergency—was based on high radiation levels in several areas of the plant. The site emergency was not announced until about 6:50 or 7:00 a.m. The declaration of general emergency—a more serious alert also involving off-site notifications—came at about 7:20 a.m. Yet the incident had actually started at 4:00 a.m., and the uncovering of the core and severe core damage occurred from 100 to 140 minutes later. Thus the off-site notifications did not come until hours after the start of the accident and more than an hour after the first serious damage to the core.
>
> This suggests that we should think very hard about how to decide when an incident or an accident, whatever you want to call it, is occurring. How can we be sure that our bases for making that decision are not too narrowly constrained by preconceived notions of what the accident is going to look like? One critical feature of the TMI accident was that it did not look anything like the design basis accident.
>
> After the fact people can say, "Well, the operator should have recognized this or the operator should have recognized that." I don't know who you have in your power plants, but we don't happen to have Ph.D.s in ours. Our staff members do what they are trained to do. They go by the book—by the lists that are given to them. And I think many difficulties would be associated with the suggestion that they should not go by the book.

Dieckamp also pointed out a related problem concerning the training of operators and writing of procedures:

> If we would stop at the point of identifying what the operators could have done and failed to do to prevent the accident, we would conclude that the operators were stupid. However, if we ask ourselves, "Why didn't they do those things?" we find that their training and their procedures specifically inhibited them from performing certain actions. And why was that the case? The plant had encountered conditions that had not been anticipated in any of the analyses, and, therefore, exhibited behavior that had not been considered in the generation of procedures and training. As a result, the operators behaved according to their training and not according to science. Had they behaved optimally or correctly, they would have been better scientists than the several hundred or thousand or tens of thousands of scientists who had not anticipated this accident before March 28, 1979. I think we ought to think very deeply about this, because what it says to me is that our ability to train the operators and write good procedures is limited by our ability to know ahead of time all the combinations and permutations of failure and system response that they could ever encounter.

Theme 4: There is a need for research on the decision-making tasks that are apt to arise in accident management.

Robert Martin articulated this theme clearly:

> If I were to look at an area that I think deserves research in the area of emergency planning, I would focus on the art, the skill, the science, and the prayerful aspects of decision making. What components does a plan need to help an individual make a decision that best serves public health and safety? Do I have to take into consideration the number of people that could be killed during an evacuation? How much information do I need to legitimately justify a decision, in a case in which both the decision and the failure to make the decision might jeopardize life and property?
>
> Decision making in the case of a nuclear accident differs from military planning and business planning. In a nuclear emergency I have to deal with an evolving accident that threatens human safety. I have to make a combined technical, political, and health decision to risk the life of people by taking some sort of corrective or protective action that may in fact jeopardize them more than the thing I am trying to save them from. I would strongly urge that IIASA apply a systems analysis approach to such decision-making

> problems. The results of such research might allow us to test our individual plans and ask, "Do the plans give us sufficient decision-making capability?" If they don't, then we can change the plans, and take such measures as requesting more data and more telemetry. But right now we don't have a clear understanding of the information we need to make better decisions, except on an event-by-event after-the-fact basis.

Theme 5: Accident management plans should be resilient to confusion.

One of the key lessons of TMI was that a nuclear accident may generate great confusion. Yet there is little evidence that any country has altered its plans since that accident in such a way as to increase resilience to confusion. John Lathrop (IIASA) put the following questions before the workshop participants:

> The impression I get from the morning's talks is that emergency plans work. I have the uncomfortable feeling that if this workshop had been held a year and a half ago, before TMI, the representative from the United States would have given a presentation not greatly different from the British presentation and the audience would probably have thought that the US plans would work. Yet at TMI the US plans did *not* work. Confusion in the first days led to a loss of the utility's credibility which in turn influenced the NRC's position throughout the accident. How are other nations' plans resilient to confusion, resilient to equipment failures, resilient to loss of credibility? Which fall-back plans are available? Which agencies could be called in when confusion causes a real problem with the perception of the accident?

Richard Pepper from the Central Electricity Generating Board in the UK responded in the following manner:

> I don't think it is possible to forecast resilience against confusion. But that is the very reason for having a plan initially. Mr. Dieckamp questioned whether a given plan can really help in an emergency situation. He and others have asked, "How realistic are these numbers? Should one wait until one has 14.5 rem in the thyroid before taking a tablet and running?" I think such questions go beyond the real purpose of an emergency plan. It is necessary to set up a system and to train people to know what to do in principle. In the chaos of the first few hours of an emergency many people are in need of support. The comfort of knowing that 30 rem to a thyroid is reasonably acceptable is something that a controller can hang on to. If he had not been given that number, he would have to turn to somebody to get it. Such figures provide

> him with guidelines on which to base his actions. I am quite sure that what will happen will be different from what the controller anticipates. Nevertheless, the guidelines give him a basis for coping.

In Harold Collins' view we should not expect to see plans change in response to TMI, because the plans are not the problem:

> John Lathrop has suggested that those of us who have spoken today probably would have given much the same presentation a year and a half ago, before TMI. He is quite right. That is because several of us, representing twenty countries, think that we have identified quite well what ought to go into emergency plans after more than four years of work on the question. This work was organized by the International Atomic Energy Agency. Several documents have been published as part of this effort [see IAEA TECDOC-225, 1979]. Because of the Three Mile Island accident, people think we should now go back and reinvent the wheel. That is not necessary. The problem in the US—and I dare say in other countries—has been getting people to follow the existing guidance. They just won't do it. I don't know what it would take to get people to put in place features of plans that we have already told people to adopt. There seems to be a great reluctance in this area.

One participant maintained that it is not possible to develop a resilient plan, that success in recovery from a rare event is determined by the human resources that can be marshalled. While his point is different than Collins', there is in fact some common ground in their two responses; the problem is not one of adjusting technical aspects of the plans, rather it is one of adjusting the plans where they interact with people—those who must accept the plans and implement them.

Theme 6: Safety cannot be maintained through plans and regulations alone. There is a limit to the size and role of emergency plans.

During the workshop it was natural to dwell on the plans and regulations involved in nuclear accident preparedness and management. But participants often made the point that such plans and regulations are not sufficient. Robert Martin stressed in his paper that a technical adequacy review will not be effective if its purpose is only to satisfy regulatory requirements; its mission must be safety. Similarly, Ernst Hampe noted, "Twenty years of experience in this field have shown me that safety cannot be assured by administration." As well, there is a limit to how large a role plans should play, how elaborate and imposing plans should be. As Godfried van den Heuvel stated,

> When I listen to all of your plans and make my notes, I think, "Well, maybe we can use a little bit of this here and a little bit of that there for our own plan; we can try to constantly improve the plan." But then I ask myself, "Must I make such a plan for the people who live near a nuclear power plant?" Of course we should discuss the make-up of a good, workable plan, but we must ask ourselves how far we can go in manipulating the people with our plans. How far can an authority go?

This point was reinforced by Harry Otway (CEC Joint Research Center, Ispra):

> My experience in planning for this sort of accident is that the more specific the plan, the more likely it is to be wrong. We seem to be tacitly assuming that emergency planning is a good thing that one can't get too much of. Is it possible to discuss the optimum amount of planning? How much is enough? At what point are we involving too much effort, perhaps even distracting ourselves from the more important issue of preventing accidents? How much planning do we really need?— maybe even none. At one extreme perhaps all we need is a mobile team of experts in crisis management, who can be sent to every crisis. If the team has directed evacuations from several types of incidents, it will know how people respond to evacuation. The team could provide advice to local officials and the staff of a particular technical facility.

While Otway stressed the need for experts in general crisis management as entire or partial substitutes for plans, Herman Dieckamp saw a need for people with technical backgrounds in the nuclear field to be rapidly available to assist in regaining control of a reactor:

> I conclude that more technically trained people are needed in the plant on a 24-hour-a-day basis. We found in the case of the TMI accident that those people coming to the site who had worked in a plant designed by Babcock & Wilcox were much more effective than those who had not, because they came on-site with a greater degree of prior knowledge. This knowledge gave them the ability to move right in and become effective very quickly. One problem that we should discuss is how to make these additional human resources effective at the earliest possible time. I think more of these resources should be on-site at time zero.

In contrast, Robert Martin warned against relying on technical experts too much:

> I think it is important to recognize the weaknesses of thinking, "If I have a super-technical person who arrives on site in his flowing white robes, he will

> be able to make all necessary determinations." This will not necessarily occur, perhaps because of the mind set of the expert or his 'best learned response'. The duty officer at TMI on the night of the accident was the plant's technical superintendent. He was qualified on Unit I and was licensed. He was in charge of all technical reviews for Unit I; in fact, he was the chairman and the leading technical expert on the plant's safety review committee. He arrived at TMI within an hour of the start of the accident, yet he didn't understand what was happening, either. I think it's a mistake to rely too much on that technical person who is going to solve all your problems for you.

Theme 7: Nuclear accident preparedness and management should be a dynamic process of social learning.

7a: In a narrow sense, detailed learning from past accidents requires deliberate institutional mechanisms. While such learning notably failed before TMI, such mechanisms are now in place to remedy this failure.

In one of the first comments made at the workshop, Herman Dieckamp listed some causes of the TMI accident, as they had been identified by the Rogovin and Kemeny Commissions (e.g., deficiencies in training, procedures, instrumentation). He emphasized as most important the finding that "the accident occurred because of a failure to learn the lessons of others." The Rogovin Report (1980) cites previous incidents similar to the initial stages of the TMI accident. One event in particular, which had occurred at the Davis—Besse Plant in Ohio, had been intensively studied by the utility, the reactor manufacturer (Babcock & Wilcox), and the NRC. Yet the institutional framework for passing on lessons learned was not effective, and the results of those studies did not find their way to the staff of the TMI plant before the accident. Several efforts have been initiated in the US since TMI to assure that lessons learned are passed on to operating plants. The point remains, however, that adequate, timely learning mechanisms require deliberate institutional effort. Apparently it required an accident like TMI to uncover the inadequacy of the learning mechanisms of the US nuclear power system.

Assuming that the necessary institutional mechanisms are effective, the learning process for design-error-related accidents can be modeled as a statistical process. Karl Ott (Working Group for Applied Systems Analysis, Köln, FRG) presented a paper at the workshop (Ott and Marchaterre 1981) that described a model of this learning process. Ott's model views particular accidents as opportunities to deplete a population of yet unknown types of accidents "lurking" within a technological system. Ott fit his model to five past nuclear accidents that had led to a broad learning experience influencing power reactor development. These accidents included TMI and the Browns Ferry fire. According to Ott's model, a TMI-type accident was "lurking" in present reactors with a frequency of one per 220 years. Learning from TMI should substantially reduce the residual design-error accident frequency, but only in conjunction with an adequate institutional learning process.

> 7b: *In a broader sense, it is not clear how well accident-management institutions learn from past accidents, i.e., effectively change themselves to better deal with future accidents.*

Roger Clarke (National Radiological Protection Board, UK) began his presentation as follows:

> I am reading here from a report: "The accident occurred during a routine maintenance operation. In the report which the Committee of Inquiry submitted regarding the accident, it was stated that the accident was partly due to inadequacies of the instrumentation provided for the maintenance operation that was being performed at the time of the accident, and partly to faults of judgment by the operating staff, these faults of judgment being themselves attributable to weaknesses of organization." [Report to Parliament on the Accident at Windscale, 1957]. So in some ways this situation was not dissimilar to TMI. Among the problems identified at Windscale were that the physicist in charge had no operating manual with sections dealing with the type of incident at hand. He had no instructions to help him, nor had he the benefit of sufficient training.

While there may not have been an opportunity to learn anything from Windscale at a detailed level that could have helped prevent TMI, Clarke's example shows that the two accidents shared some general features. It may be too much to expect that general lessons learned (e.g., "training is important") are learned so well that no future accident could be attributed to poor training. At the same time, the recognition that there are similarities between accidents does raise the question of how well accident management institutions learn general lessons from past accidents. The workshop participants reached no consensus opinion on this issue. Comments ranged from "no, they don't learn" to "yes, they do" to "they react, but not necessarily in the right direction." As a "no, they don't" example Harold Collins made the following comment:

> Within a four-year period in the United States, we had two serious nuclear power plant accidents. The first occurred at Browns Ferry; it was started by a workman testing for air leaks with a candle. He ignited instrumentation and control system wiring insulation and nearly caused a very serious accident. Dr. Stephen Hanauer, chairman of the NRC investigation group, remarked at one point during the investigation, "It was

> like a mild heart attack, maybe it woke us up." Well I submit to you that we never were woken up by Browns Ferry. Nobody woke us up around the world, and nobody woke us up in the United States. All kinds of investigative reports were put together, a few things happened within the NRC (a brand new agency at that time), and a few things happened in the nuclear utilities. But there really wasn't much of a change in the way people did business in the plants. The Browns Ferry accident was a serious event, and we should have learned much more from it. It could have resulted in radiological releases to the environs from two units. We were very fortunate that this did not occur. Then, of course, four years later, almost to the day, the Three Mile Island accident took place. Two days earlier I had received a letter from a county official, which commented on one of our guidance publications. The official took great issue with the notion of emergency planning zones. He asked, "What do we need all this for? Nothing is ever going to happen."

Yet the same workshop participant stressed that TMI, unlike Browns Ferry, had really made a difference:

> Those of us who have been in the business always believed that putting emergency plans in place was the proper thing to do. But it was difficult for us to convince many state legislatures, governors, and so on that a nuclear power plant accident really could occur and that they needed proper emergency plans and resources to respond in the event of an emergency. Since Three Mile Island, of course, the whole picture has changed. States that had been dragging their feet on the emergency planning activity are now all jumping on the bandwagon.
>
> Ten years ago, when I first became involved in this field, about three people in the whole Atomic Energy Commission were working in the emergency planning and preparedness area. At that time, when we presented accident scenarios and a lot of "what if" events, people smiled and essentially told us, "it's very nice that you fellows are doing all of this, but why don't you go back and do a little more work, and come see us in about five years?" This type of attitude pervaded the entire emergency planning and preparedness activity in the United States. Since the accident in Pennsylvania, I can assure you that the entire picture has changed drastically.

In his paper, Robert Martin provides evidence that since TMI the NRC has substantially increased its efforts to identify, evaluate, and resolve deficiencies at nuclear plants. In Martin's words, this increased activity represents "the agency's recognition that the TMI accident, as it evolved, may well have been prevented, if such measures had been pursued more aggressively earlier." Yet, during the discussion sessions, Martin pointed out that not all the changes implemented in response to TMI may result in actual improvements in nuclear safety:

> An agency under attack may make a number of changes because it feels pressure to institute change. These changes require critical review by both the industry and the agency. Consider the decision to place resident inspectors at every operating facility in the United States. A large number of attributes of the resident inspector program have not yet been identified. For example, what role would such inspectors fill in an emergency? The agency maintains that they would continue to serve their normal role, i.e., to assure that the licensee is carrying out its function. However, in the first key minutes or hours of an accident, the very presence of the inspector presents a host of new problems. For instance, if an operator goes to perform a manipulation, he might look at the inspector; if the inspector does not react, is it unfair for the operator to assume that he has the tacit approval of the Nuclear Regulatory Commission to carry out that manipulation? Perhaps the inspector simply did not understand what the operator was doing.
>
> In the process of evolving emergency planning measures, one has to test every suggested change to see if it contributes constructively to overall emergency planning. Making a lot of changes could be like putting band-aids on a cancer. It may not be the proper treatment for the disease.

7c: The rarity of nuclear accidents hinders accident management learning.

As discussed below, the events at Three Mile Island exposed a basically unanticipated type of accident, one that developed slowly and in a confusing manner. It was unanticipated because the accident management plans that were then in effect were designed to manage a select set of accidents: hypothetical accidents and the very few accidents that actually had occurred. Of course, both hypothetical and historical accidents were well understood: the former because they were generated from the minds of analysts, the latter because they had been thoroughly studied. Because of the rarity of nuclear accidents, accident management plans were geared to well-understood accidents. It is not surprising that such plans proved inadequate when applied to an on-going accident that was poorly understood by the participants, i.e., Three Mile Island.

The rarity of nuclear accidents heightens the importance of international exchanges of experiences. In order to make the most effective use of the small amount of existing nuclear accident experience, emergency planners should be prepared to apply lessons learned from an accident in another country to their own country's accident management system. Yet institutional differences can hinder this transfer, as was illustrated in one of the workshop discussions. After hearing a description of the role of the US federal government in the TMI accident, a participant remarked from the floor that such a federal role would be considered undesirable in his country, and was therefore not foreseen in its accident management plans. However, this participant overlooked the fact that the role of the federal government during the TMI accident had not been foreseen in the US plans, either. The confusion and uncertainty that marked the first days of the TMI accident led to differing and continually changing reports about plant status. The conflicting reports lessened the credibility of the utility, which in turn caused the federal government to play a much larger role than had been planned. A very important lesson to be learned from the TMI experience is that confusion and uncertainty can lead to a fundamental rearrangement of agency roles. Yet it is very difficult to apply that lesson to another country's accident management system.

A third difficulty caused by the rarity of nuclear accidents relates to the often long time lapses between accidents; this has a negative effect on motivation to maintain preparedness. This difficulty was illustrated by Harold Collins (see Theme 7b above) when he mentioned that four years after Browns Ferry (and a few days before TMI), an emergency planning official maintained that nothing was ever going to happen. An emergency management agency official who attended the workshop stated that he had to seek budget increases within three to six months following a disaster; after that time interest would wane. TMI has caused a marked increase in government agencies' enthusiasm for emergency preparedness, but it remains to be seen whether that interest will continue at an adequate level over the (possibly) several years until another nuclear accident occurs.

Theme 8: Discussion of nuclear accident management may involve the broad issue of the acceptability of nuclear power.

Discussions concerning the effectiveness of nuclear accident management plans may be affected by the participants' biases in favor of or against nuclear power. These biases may make it difficult to analyze the effectiveness of nuclear accident management systems in a way that may be generally considered objective. Persons opposed to nuclear power may be markedly critical, either out of genuine concern or to strengthen their stance as advocates of alternative energy strategies. Similarly, putting emphasis on nuclear accident preparedness can be construed as promoting nuclear power. As Joanne Linnerooth (IIASA) suggested, the very activity of emergency planning may be viewed as a strategy to win public confidence:

> What are we trying to get across to the public with the concept of emergency planning? A few points made this morning may throw light on this question. First, the

> accident management plans that we have been talking about this week probably won't work. The human factor, the confusion, and many other factors have not been taken into account in the simulation models or the various plans we have been discussing. Second, even if accident management plans do work, they probably won't help too much. We have to ask ourselves what other reasons there may be for making elaborate emergency plans. One answer is suggested by the history of nuclear power. In the beginning the strategy of those promoting nuclear power seemed to be to tell people that there are no risks, that the probability of an accident is very low. But now that we have had TMI, the credibility of that line of thought has diminished. It is difficult now to tell people that there is no chance of an accident, because they have already seen two very significant ones in the last few years. Perhaps promoters of nuclear power are now concentrating on emergency planning because they recognize that the public is concerned with the consequences of accidents and is not satisfied by assurances that accidents rarely occur. Perhaps those promoters are saying "Let's now focus on the consequences and let's convince the public that the consequences of accidents will be taken care of because we have emergency plans."

Theme 9: Because nuclear accident management is embedded in a political context, the process *of ensuring preparedness is important.*

Theme 8 touched on the link between the acceptability of a nuclear accident management system and the acceptability of nuclear power. This link has an important implication: the acceptability of nuclear power as an energy source may be related to the perceived legitimacy of the process that establishes and maintains the accident preparedness and management mechanisms. As David Fischer (Institute of Industrial Economics, Norway) stated,

> The question of the visibility of the planning process is important. I would argue that if the public is going to accept emergency plans, it must be able to accept the planning process used to generate the plans. Therefore, this process needs to be well publicized and visible. Improved visibility with heightened public confidence in the planning process would counteract the tendency of the media to attempt to show as scandals the conflicts in perceptions and decision making regarding nuclear accident management.

Harold Green discussed the relationship between the history of the political process affecting nuclear power in the US and the current critical reactions to TMI:

One of the Kemeny Commission's conclusions was that the NRC appeared to be more concerned with the welfare of the nuclear power industry than it was with regulation. I have, from time to time, used the analogy of the "overprotected child" in this context. Such a child is so protected by loving parents from all conceivable risks during his early years that he is not able to "make it" in the ordinary world of risk when he reaches adolescence. Nuclear power has had such a set of "loving parents", namely the Atomic Energy Commission, then ERDA [Energy Research and Development Agency], DOE [Department of Energy], NRC, and, perhaps the most loving of all during the years, the Joint Congressional Committee on Atomic Energy. These agencies really sought to protect their tender infant from the buffeting of the normal political processes operating in the United States.

Atomic energy has thus had a very peculiar political history in that country. There has never been an exhaustive debate or discussion within Congress about the risks and benefits of nuclear power. And yet, a national commitment to nuclear power was made somewhere along the line. In my opinion, this fact underlies the intense political controversy about nuclear power in the United States. What we are now experiencing is the debate that was lacking earlier—the kind of debate that I think is inevitable in the American political system. Such a debate is bound to come sooner or later, and in the case of nuclear power we are having it "later," at a time when the industry is least able to afford it.

We must also realize that most people who have been involved in the atomic energy scene in the United States over the years have been "insiders", i.e., experts in one sense or another. It has become increasingly clear that when people who are not "insiders" become involved in questions about nuclear power they tend to become antagonized and object to what they see as the way the system operates. I do not think we should pay too much attention to the criticisms that these people level. The serious problem is that the system is constructed so as to almost inevitably produce negative perceptions among "outsiders." I do not know of any "outsider" who has reacted with kind words when exposed to the technology and regulatory structure of the nuclear industry. From the outset it seemed inevitable to me that the Kemeny Commission—which consisted almost entirely of people who knew nothing about the nuclear industry—would emerge with basically hostile, skeptical, and indeed, in some respects, inaccurate perceptions.

But I think we ought to recognize that this is natural. I hope that those concerned about the future

> of nuclear power in the US will give serious thought to the type of reforms required for normalizing the political processes and developing the nuclear industry on a solid basis, to overcome the overprotective childhood that the industry experienced. To use a medical analogy, I think we need to lay nuclear power down on a couch and perform a psychoanalysis.

Theme 10: Nuclear accident preparedness and management cannot reduce the risk of nuclear accidents to zero.

This statement may seem obvious. Yet most of the workshop papers and discussions tended to dwell on accidents for which accident management measures would be straightforward and effective, i.e., reasonably well-understood accident situations with adequate warning to carry out countermeasures. However, it is not hard to imagine accidents where there would be no adequate warning. In addition to the typical example of a rapid core melt, consider a slow, TMI-like accident, where the operator remains too confused to sound a definite alert until shortly before a major release.

Danzmann presented the only paper at the workshop that assessed the health effects to the population that could occur during a nuclear accident in spite of countermeasures. As his paper, which reported on the main results of the German nuclear power plant risk study, makes clear, significant nuclear accident risks remain even after accident management countermeasures. Thus, in the interest of candor (see Chapter 16), nuclear accident management plans should clearly address possible limitations to their effectiveness as well as their obvious benefits.

In the midst of all the discussions of emergency plans at the workshop, it was easy to lose sight of the fact that one day someone in the room could find himself in an accident situation in which all the carefully planned emergency measures in the world would not keep lives from being lost. As Godfried van den Heuvel reminded the participants,

> It is fairly easy to make an emergency plan, but no one talks about the problems that arise for a government authority when a meltdown really does occur. I think the most severe accident is possible. Terrorists could do something unexpected to a power plant, creating a situation that no one can forecast.

Theme 11: The human element in nuclear accident management deserves more attention in emergency plans.

Problems of human error, operator stress, and operator training were frequently discussed during the workshop. But perhaps more attention should have been devoted to broader problems of human behavior. Take, for example, the problem of operator incentives. A plan cited by Harold Collins requires operators who have become confused about the status of their plant to notify authorities within 15 minutes (see Theme 2e). Is it realistic to expect compliance with such a requirement, given the probabilities of an accident and the actual incentives facing an operator? An operator who may face career penalties if he sounds a false alarm may be very reluctant to notify authorities on the basis of ambiguous information. This reluctance may cause him to act against the best interests of public safety. Clearly the incentives of an operator facing such decisions should be examined and perhaps adjusted to ensure that appropriate decisions are made.

A more problematic point concerns risks faced by the operators. Early in the workshop a question about TMI addressed to Herman Dieckamp spurred a discussion on this topic:

> GYLDEN: What was the most pessimistic contingency that you ever considered during the accident?
>
> DIECKAMP: I think we worried most about the possible need to evacuate the site.
>
> GYLDEN: What would have been the criterion for such an evacuation?
>
> DIECKAMP: I think you can imagine the kinds of conditions that could raise that possibility. The criterion would simply be unacceptable risk. This becomes a very difficult question.

While Dieckamp referred to a deliberate evacuation of the site, ordered by accident managers, this interchange raised the possibility that the operators might decide to leave on their own initiative. Joanne Linnerooth brought up this issue following Dieter Kaspar's presentation:

> The stress situation during an accident is very high. I have noticed that most emergency planning relies heavily on plant staff to perform many duties. I wonder if Dieter Kaspar's simulation model has considered the chances that a great number of these people might panic and simply run? There would be a high incentive to get out of the area.

Dieter Kaspar (Ministry of Labor, Health, and Social Welfare, Baden-Wuerttemberg, FRG) responded, "Yes, certainly there will be very much stress. I don't think one can do much to avoid it. Perhaps training would help." In this context Robert Martin presented an additional reason why the operators might leave:

> When we did the investigation on TMI, the operators initially said that they had no concerns about remaining in the control room themselves. But during the interviews it became clear that if their families were forced to evacuate, they would not stay behind and let their families leave the area without them. When one

> evacuates an area, one may very well be evacuating the wife and children of the people who are in the control room. This introduces a different level of stress and a different set of circumstances; they may not be willing to "go down with the ship"—they may not stay. This possibility is a feature that has not been included in the discussion of emergency plans.

Later in the workshop Siegfried Bernhardt (Gemeinschaftskernkraftwerk Neckar GmbH) made a related point about the unanticipated consequences of evacuations.

> Although we have to be prepared for an evacuation, I do not believe that it is a very good measure. For example, the river flood control operators working for our water authorities have said, "We would not stay here during a nuclear accident-related evacuation." Who will then regulate the water level in the river? Dams could break and cities could be flooded. Who knows what other secondary failures will occur as a result of those evacuations? There are many more problems to be expected than simply handling the traffic and finding houses for the evacuees.

Yet another aspect of the human element was brought up by Godfried van den Heuvel in a discussion of some technical probabilities of serious nuclear accidents.

> The danger of terrorist action is a compelling reason for us to make emergency plans. I don't know if your forecasting of risks includes capture by a very small group. You can make calculations about technical risks, but the human factor, as has been mentioned, can do strange things that are difficult to forecast. You have to take account of this human factor in your emergency plans.

Clearly, accident management plans should be prepared to handle these aspects of human behavior. The unanticipated departure of key staff or terrorist attack are not readily amenable to prediction or analysis, but these problems could so drastically affect the effectiveness of an accident management system that they must be considered in any responsible planning process.

Theme 12: Although exercises are important, it is difficult to carry them out effectively.

Baas and Bošnjaković point out in Chapter 13 that the rarity of nuclear accidents increases the importance of exercises in testing and maintaining nuclear accident preparedness. If an exercise is to be effective, it should include the aspects of an actual accident that affect human behavior most significantly. One such aspect is stress. Otway and Misenta emphasize in Chapter 17 the impact of stress on operator performance: the absence of stress in normal operation lowers operator alertness, while heightened stress in an accident impedes performance. They suggest in their paper that frequent surprise exercises would be a good way to increase operator alertness and, if they are realistic exercises, to allow the operators to improve their tolerance for stress. Yet it is not easy to design exercises that are authentically stressful. Another important aspect of accidents that affects human behavior is confusion, as TMI showed. Yet again it is very hard to generate authentic confusion in an exercise, even if only a limited number of participants know about the exercise in advance.

The difficulty of running an effective exercise was often raised at the workshop. In his presentation Dieter Kaspar described an elaborate and thorough exercise carried out in the FRG (see Chapter 12). The exercise was carefully designed, capturing many features of a real accident. For example, emergency planners did not have a script, but received instead a series of messages from the reactor crew, just as in an actual accident. At one point a recommendation to evacuate was made on the basis of incomplete information, a situation that would also be apt to happen in a poorly understood accident. Yet Robert Martin took issue with the authenticity of the FRG exercise, contrasting some aspects of the exercise with the events at TMI:

> We should look very closely at staff behavior in the stress situation of an accident. Consider the timing in the German exercise. I have the distinct feeling that in the exercise the authorities were notified through normal channels and that the time that elapsed between the notification and the response to the notification was very short. [Editor's note: In fact the delay was only two minutes.] I don't think that is realistic. Our investigation at TMI showed that once the accident was recognized it took five staff members to make the phone calls, tying up all the outgoing telephone lines at the plant. The people that the plant staff were required to notify would not accept the fact that they had received a basic series of data. They wanted and needed more information. They said, "Are you sure, is it really that way?" The phone calls that theoretically were to take 2 minutes in reality took 15 minutes, 30 minutes, 45 minutes, or an hour of continuous data exchange. It is not realistic that in the case of a real accident the staff at an emergency center will pick up a phone, listen to someone say, "I've just had a LOCA. I've released 15 thousand curies of iodine, I will call you back later with additional data," and then smoothly take action in response to a statement of that sort. It simply will not work that way.
>
> We also found that the receiving organization, i.e., the people who were given data during the notifications, did not have a preset or preestablished list of the types of information that they needed to have.

> Many of the questions they asked were unrelated to the actions that they had to take at that time. They wanted to know "why it occurred." You don't need to know "why it occurred." You only need to know what occurred and what actions should be taken. But much of the time of both the NRC contact and the licensee was really spent examining "why" it happened, not "what" happened. In a real emergency you are interested in knowing "why" and this ties up valuable time and people. In a drill, you only want to know what happened and then everybody runs around the way they are supposed to. In the real case, this won't happen, at least not without a lot of experience and training.

CONCLUSIONS

Summary of Themes

There is no room for complacency in nuclear accident preparedness. As the number of reactors increases and as the early reactors age, the past rate of very roughly one significant accident every five years may increase. The persons with perhaps the least reason to be complacent are the government authorities who, in the event of an accident, would be faced with difficult decisions concerning countermeasures (e.g., shelter vs evacuation vs no action)—decisions that involve the weighing of the social risks of each alternative. These decisions must be made under time pressure, often on the basis of incomplete technical accident assessments.

The Need for Resilience to Confusion

Three Mile Island exposed a basically unanticipated type of accident, one that developed slowly and in a poorly understood manner. This forces us to ask how many more unanticipated accidents may be associated with the technology, and how we can best prepare for them. The uncertainty and confusion of TMI caused anxiety among the general public, contributed to a rearrangement of the roles of the agencies involved, and caused great difficulties in the communications necessary for both on-site and off-site accident management. There is a clear need to redesign management plans to make them more resilient to the confusion generated by such an accident. The plans must provide clear roles for all agencies, predecide as many decisions as possible, and aid accident managers in making decisions based on the often limited information actually apt to be available in the course of an accident.

Some aspects of current plans are definitely not oriented toward handling the extreme uncertainty that may be associated with a nuclear accident. For instance, countermeasure guidelines based on projected dose assume an accident that is understood clearly enough to project that dose. As well, criteria for determining whether an accident is taking place are sometimes constrained by preconceived ideas of what an accident is going to look like.

One of the most important lessons of the TMI experience, then, is that accident management plans must be able to deal with confusion and uncertainty. Yet it is difficult to tell if the plans of any country are in fact resilient to these features of accidents, or if changes incorporated since TMI have made the plans more resilient. Perhaps the most promising way to increase resilience is to pay most attention to the aspects of plans that involve the rapid marshalling and organization of people with appropriate expertise.

The Need for Institutional Mechanisms for Learning from Rare Events

TMI showed that adequate accident-to-accident learning at a detailed engineering level and at a more general level requires deliberate institutional mechanisms. However, the rarity of nuclear accidents makes it difficult to modify plans and institutions in response to actual accident experience. Not only are there few accidents to learn from; there are long periods of time between accidents, during which lessons learned tend to fade as interest in accident management wanes. In addition, lessons from specific accidents are often difficult to apply to different countries and reactors.

The Need for Candor

Because issues in nuclear accident preparedness and management are embedded in larger questions of the acceptability of nuclear power, discussions on the topic may be affected by biases for or against this energy source. One consequence of these political factors is that the process of accident planning, including the degree of candor, is important to the acceptance of nuclear power. Because accident preparedness cannot reduce nuclear accident risks to zero, candor is essential.

The Need to Consider the Human Element

Because the human element contributes in a major way to the risks that remain associated with nuclear facilities in spite of accident preparedness, plans must specifically address this element. Included here are the problems of deliberate or unanticipated departures of key staff, operator behavior under stress, and terrorist action. The human element must be taken into account in the exercises and drills designed to maintain preparedness, although it is extremely difficult to design an exercise that in fact prepares its participants for the surprise, stress, and confusion of an actual accident.

The Special Problem Posed by Rare Events

Nuclear accident preparedness and management challenge human abilities to develop and maintain institutions for managing the risks of a rare event. Such institutions must handle an essentially unique combination of problems. It is difficult to incorporate lessons learned from rare events into established institutions, to test preparedness, and, above all, to develop really effective plans. Accident management plans have been developed on the basis of hypothetical accidents and the few accidents that actually have occurred. Yet while hypothetical and past accidents are well understood, a future accident is apt to be poorly understood while it is occurring. It may be so poorly understood that it is difficult even to recognize when it starts. This was the case at TMI.

But beyond these problems, the fact that nuclear accidents are rare makes it extremely difficult to maintain preparedness. The long time periods between accidents, especially between accidents in a given country or involving a given type of reactor, mean that an individual's incentives for career advancement or local government officials' concerns for staying in office may not be compatible with maintaining effective preparedness.

Can We Maintain Preparedness?

Anyone who has witnessed recent achievements in national space programs can appreciate the achievements of technical organizations in obtaining reliable performance in very complex systems, even when the human element is a part of those systems. But these examples involve one program per country, vast expense, and systems that are in critical operation for only a few hours. Nuclear accident preparedness involves several facilities per country, economic constraints, and base load systems that operate essentially all of the time. The systems considered here must maintain preparedness for a potentially catastrophic rare event in the course of a routine operation—an operation so routine that it was once described as "just another way to boil water".

As this discussion has pointed out, nuclear accident preparedness and management involve a unique combination of problems. It is no easy task for institutions to develop effective plans, to adapt those plans in the light of scarce experiences, and to test and maintain preparedness for a rare but potentially costly event. The accomplishment of this task is a key issue in the acceptability of nuclear power—a promising and perhaps necessary source of energy, with many political, environmental, and economic advantages.

Most participants at the IIASA workshop felt that it is within the realm of human and institutional capabilities to maintain adequate preparedness for nuclear accidents. Many of the following papers reflect this point of view. However, unique institutions must be developed and maintained to overcome the obstacles to preparedness. In the aftermath of TMI, a clear need has been identified for fundamental and innovative change in politically established organizations. To some degree, these changes have been set in motion. However, as the reader goes on to the following papers, reviews the themes discussed above and the changes called for by the lessons of TMI, he would do well to keep in mind the closing paragraph of the Rogovin Report (1980):

> With every passing day, TMI draws less attention. [Current crises] push the nuclear safety question into eclipse. Just as the last major reactor accident, the Browns Ferry fire, slipped beneath the surface of the sea of daily concerns 4 years ago, so can Three Mile Island join it in the coming years. It will take dogged perseverance in the nuclear industry and in the Government to truly learn the lessons of TMI. We are not reassured by what we see so far.

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II. THE ACCIDENT AT THREE MILE ISLAND: THREE PERSPECTIVES

While the IIASA workshop did not focus only on the accident at Three Mile Island, that event provided an instructive example of decision making under extreme uncertainty. There have been other nuclear accidents, but none has so dramatically combined problems of population safety with the management of a confusing, slowly developing accident. In this Section three key decision makers involved in managing the Three Mile Island accident present their interpretations of the events that began on March 28, 1979.

The accident itself is not described in detail here. The reader is referred to the reports of the Kemeny, Rogovin, and NRC Commissions for excellent and exhaustive reviews of the accident (see p. 12). Instead, the papers in this Section emphasize organizational and procedural problems in accident preparedness and management.

A valuable component of the workshop was the candor of the authors of these papers—representatives of the organizations most deeply involved in the accident, namely, the owner/operator, the regulator, and the emergency management agency. While each paper looks at the accident management problem from a different perspective, a common element is that all three authors have actually been through the experience of coping with a nuclear accident.

The first paper, written by the President of General Public Utilities, highlights particular accident management problems encountered at TMI, touching on communications, interactions with the regulator, and the organization of technical support. The second paper, contributed by the Director of the Nuclear Regulatory Commission TMI Support Staff, explains the functions of the NRC at the accident site, including diagnosis, technical and logistical support, and approval of unusual operations. The third paper, authored by the Head of the Pennsylvania Emergency Management Agency, recounts lessons learned from TMI from the point of view of an administrator used to general emergency management, who is suddenly faced with a new kind of accident.

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THE ACCIDENT AT THREE MILE ISLAND FROM THE PERSPECTIVE OF THE OWNER/OPERATOR*

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General Public Utilities Corporation, USA

INTRODUCTION

In this presentation I would like to share my impressions of how the Three Mile Island accident unfolded and the kind of organizational responses that occurred in various phases of the accident. I do not presume to tell you what is the right way to respond to accidents or to organize for them. What I would like to do is to describe the sequence of events, to give you a basis for assessing what you think is valuable and important. I must say that I feel like the third blind man to examine an elephant this afternoon.** I do have one advantage that I am not sure this parable included, i.e., I have heard the explanations of the other two blind men. Perhaps when you take all three discussions together, you will obtain a pretty good explanation of what happened.

I would like to make it clear that I do not intend to argue with the comments of the other speakers. In general I find myself very much in agreement with their characterizations of the accident, though of course there are always different impressions to be gained from different points of view.

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*Editor's Note: This paper is based on an edited transcript of the author's oral presentation. It has been edited only very lightly, in order to preserve his general tone and informal speaking style.

**While this was the last presentation of the three in this Section, the author's short description of the accident makes it appropriate to place this paper first.

DESCRIPTION OF THE ACCIDENT

Because some of you may not be too familiar with the detailed time sequence of the accident, I would like to outline some of its important features. One critical characteristic of this accident was its protracted time scale—not only the time scale of the physical aspects of the accident, but also the long interval during which General Public Utilities Corporation (GPU) as management, the Nuclear Regulatory Commission (NRC) as regulators, and others began to realize what had happened and what future challenges would be involved in responding to the accident.* Let me begin by briefly outlining my perception of the major time phases.

As is well known, the accident started at 4:00 a.m. on Wednesday March 28, 1979, with a feedwater shutoff. The plant staff should have been able to handle this malfunction. The crucial problem occurred during the ensuing period when a stuck valve caused a net reactor coolant inventory loss, and the operators did not recognize this further malfunction. One can speak at length about reasons why the operators failed to recognize the situation. This would be an important topic for a discussion about accident prevention, but I will concentrate here only on the accident itself. The critical events were the overheating of the reactor and the release of fission products. The bulk of the damage occurred between about 5:40 a.m. and the time when the block valve was closed—about 6:20 a.m. Before this period the reactor coolant pumps were circulating a two-phase mixture of water and steam, and the core was probably being reasonably, though not perfectly, cooled. When the last pump was turned off at about 5:40 a.m., the water and the steam phases separated and the core essentially became uncovered and overheated.

At about 7:00 a.m., shortly after monitors began to indicate a potential for releases of radiation, appropriate off-site authorities were notified. These notifications conformed to previously established criteria based on gross measurements of radiation in the containment vessel. There has been much discussion about the timing of these notifications, i.e., whether the operators should have recognized the situation earlier. I think we should examine this question by asking, Did the operators perform according to previously established procedures and the requirements set forth in the emergency plans? The answer is affirmative, in terms of their notification of the NRC, the Pennsylvania Emergency Management Agency (PEMA), and others. Still, the question remains whether or not the operators should have been able to recognize earlier the potential seriousness of the situation. They did not. They acted on the basis of the identified requirements in their emergency plans.

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*General Public Utilities Corporation is the parent company of Metropolitan Edison (Met-Ed), the operator of the Three Mile Island plant.

The next phase of the accident lasted from the morning of March 28th to approximately 8 o'clock that evening, at which time a reactor coolant pump was successfully restarted and the plant was returned to forced circulation. During the period preceding the restarting of the pump the plant operators struggled with significant amounts of noncondensible gas; it was very difficult for them to understand how the plant behaved, how it responded, how to get rid of that gas, and how to deal with what appeared to be a steam bubble. Finally, after deciding simply to inject water, they got to a point where the reactor coolant pump could run. With the pump restarted, the operators achieved a period of stability—apparent stability.

It is important to recognize that during the 16 hours from the beginning of the accident to the pump restart—particularly the early time period—the operators did not have the ability, for a range of reasons, to fully diagnose what was happening. The plant was behaving so unusually, so far outside the bounds of normal definitions of plant behavior, that the operators just could not understand the situation. This in turn led to problems with the evaluation or synthesis of observations about plant performance within the plant and subsequent communication of this information to people outside the plant, including both company management and regulators. The communication of plant status and plant behavior was so inadequate and confused that the outside world as well lacked a full recognition of what was going on.

The following phase in the development of the accident covered a rather quiescent period lasting from Wednesday evening, March 28, until about 8 a.m. Friday, March 30, when a major release of radioactivity occurred. During this time period the pump was running and the plant seemed to be in a reliable cooling situation, although there was a softness in the system. The presence of the hydrogen bubble was identified and analysis of its features began sometime late Thursday night or very early Friday morning. Things seemed to be stable. However, it was not recognized that the presence of the large quantity of noncondensible gas (including hydrogen) dissolved within the coolant was affecting the plant's external support systems. Gas was building up in the letdown tanks, then leaking out as it was transferred to the waste decay tanks—a transfer that was necessary for maintaining systems operations. It was this process that resulted in the release of radiation that caused so much concern Friday morning.

As I would like to focus here on the organizational aspects of the accident, I will be very brief in summarizing the remaining phases of the accident. Friday was marked by a communications problem stemming from the release of radioactivity early in the day and subsequent reactions to it. The period from Friday evening through Sunday, April 1, was dominated by concern about the possible flammability of the hydrogen bubble and strategies for diminishing the size of the bubble. The next milestone occurred on April 27, when a transition was made to cooling by natural circulation, so it was no longer necessary to operate the pumps for cooling. At this point it became possible to think in terms of a cold shutdown. During the 28-day period from March 31 to April 27 the very large amount of fission products released into the primary cooling circuit inhibited the use of the decay heat removal system that would normally be used for putting the plant into a cold shutdown state. There was a great reluctance to expose the external parts of the plant, i.e., the auxiliary building, to the intensely radioactive primary coolant, which would have occurred if the normal decay heat removal system had been used. As a result it was necessary (and still is necessary) to remove heat from the plant by means of a steam generator through the secondary system to the condensor and finally to the environment.

ORGANIZATIONAL ASPECTS

Let us turn now to the organizational problems that arose in managing the accident. The organization evolved through various stages, and I will attempt to superimpose these stages onto the brief account of the accident provided in the foregoing section. Let us begin with the first three days of the accident, from the point of view of the plant. The central problem was that the plant staff did not possess sufficient technical capability to look at all the events that had occurred and all the conflicting parameters in the available data, to somehow reach the simple conclusion that the core was so overheated that fuel cladding was oxidized, hydrogen was released, and the core was in a state of disarray. That summary picture could not be pieced together for roughly three days. Once that conclusion was deduced, it significantly influenced the impressions and the attitudes of people outside of the plant in terms of the need to quickly supply support.

In order to understand some of the problems of accident management during the first days of the accident, we have to look at the lines of communication—both the intended lines and the actual ones. As indicated in Figure 1, communications from the plant were supposed to follow three paths. The first path to be established provided for communication between the plant, the management of the operating utility (Metropolitan-Edison (Met-Ed)) and GPU. The second communications path linked the plant to the Pennsylvania Emergency Management Agency (PEMA), the State Bureau of Radiation Protection (BRP), and the office of the Pennsylvania Governor. The emergency plans called for the plant staff to analyze the radiation situation and to communicate their findings to BRP and PEMA; the government was then to make decisions about evacuation or other protective measures, and to disseminate all relevant information to the public. This was not a bad circuit for communicating actual radiation measurements outside the plant. However, I am sure that it was an inadequate circuit for communicating to PEMA or BRP how continuing plant operations could create some vulnerability or probability for future releases. The emergency plans did not anticipate the need to be able to look ahead and say, "Continued operation is going to result in continued generation of gas, which in turn

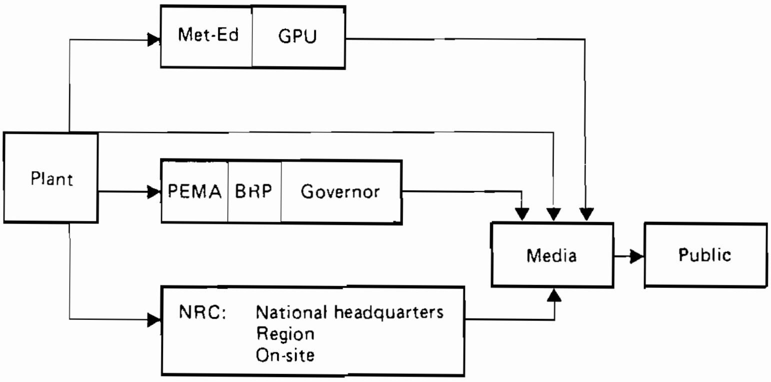

Figure 1. Communications paths between the Three Mile Island plant and Metropolitan-Edison (Met-Ed), General Public Utilities Corporation (GPU), Pennsylvania Emergency Management Agency (PEMA), Bureau of Radiation Protection (BRP), Governor of Pennsylvania, Nuclear Regulatory Commission (NRC), the media, and the public. These paths were in effect on March 28th, 29th, and 30th, 1979.

is going to stress the systems to the point where we have to release gas." The need to predict events with some uncertainty was not recognized until the events actually happened. The third communications circuit linked the plant with NRC headquarters in Bethesda, near Washington, with the NRC regional office in Philadelphia, and with NRC staff on site.

Of course, each of the paths involved the communication of information that was a little bit fuzzy, due to the limited ability of the plant staff to understand the meaning of the events that were occurring. Another problem was that communications from each involved party then went to the media and subsequently to the public. There was no good, solid communications system that put all this information into the proper context before the public was told what to expect and what to do. We found ourselves with several communications links to the media, which bypassed any organized system, and which caused a great deal of concern in the public early on with more or less unfiltered random thoughts.

In the early stages of the accident we at GPU thought that the plant had gone through some kind of shutdown, probably accompanied by some local overheating of the core and some release of fission products or gases from ruptured fuel claddings—implying that fission products and gases had leaked into the cooling system, and to some degree into the containment. We were also aware, quite early on, that there had been some loss of water through the failed-open pilot-operated relief valve. On the second day of the accident, the 29th of March, we dispatched a team of about 6 or 8 specialists to the site to begin a post-mortem analysis of the accident, i.e., to study why it happened, what could be done to prevent it from happening in the future, etc. But when the team arrived at the accident site and began talking to the plant staff, piecing together various inputs, it soon became apparent that the fuel materials had been very badly damaged and that it was necessary to contend with a large volume of gas.

As of the 30th of March two different sets of technical staff were present at the plant: the technical support from GPU and the NRC staff members who had begun arriving at the site. This situation is depicted in Figure 2. Beginning on March 29 we found that the situation at the plant had an insatiable appetite for analysis, contingency planning, what ifs, procedures, plans, fallbacks, and the like. The level of support effort and the kinds of problems faced are described in a paper by Long, Crimmins, and Lowe (1979). For a while everybody sent by GPU to the site became absorbed in the technical support operation, which went on around the clock, in two twelve-hour shifts, and provided direct support to the plant. As the NRC staff members arrived at the site, they began to quiz the plant people with such questions as, "What's going on? What are you doing about this? How about this? How about the other?" The NRC soon became nervous because it was not getting good answers, or the best possible answers that it could have expected. The NRC somehow was not fully aware that a GPU backup support team was in place. The level of information possessed by the NRC was limited by the inability of the plant staff and the technical support staff to adequately translate what was going on.

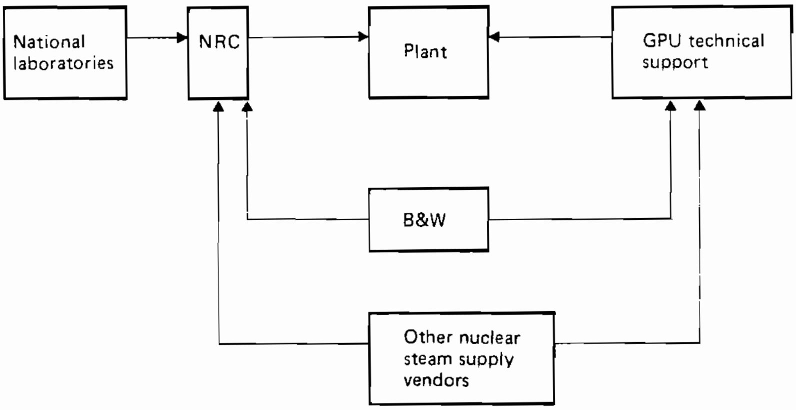

Figure 2. Groups providing technical support to the Three Mile Island plant on March 30th, March 31st, and April 1st: National laboratories, Nuclear Regulatory Commission (NRC), General Public Utilities Corporation (GPU), Babcock & Wilcox (B&W), and other nuclear steam supply vendors.

One of the problems that arose during this period stemmed from the overlapping actions of the GPU and the NRC groups. For instance, the GPU technical support group contacted Babcock & Wilcox (B&W)—the nuclear steam supply vendor for Three Mile Island—and other nuclear steam supply vendors. At the same time the NRC began to contact their consultants, B&W, and other nuclear steam supply vendors. At this point we underwent a day or two when the system was not only strained, but potentially overstrained, by having more people asking questions than answering questions. One conclusion that should be drawn from this is that a plant dealing with such an accident needs a tremendous amount of support; this support should indeed aid the plant and not just divert energy and resources. When we called General Electric or Combustion Engineering they would often react in the following way, "But we have already talked to the NRC about that. Who is asking what question? Whose question should we answer?" There were also dual circuits of communication with B&W. It is clear from this experience that it is necessary for participants to coordinate their efforts very quickly and to assign priorities to questions, so that important procedures can be carried out without diverting energy to just asking or answering an infinite variety of questions. At TMI this sort of questioning occurred with the greatest intensity on March 30th, March 31st, and perhaps April 1st. As time went on, people began to communicate better with one another and some of these problems became less intense.

The release that generated the most concern occurred on Friday, March 30th, during the period of inadequate communication. The most significant feature of that event was not the release itself, but the fact that the problems it caused could have been prevented by better communication. The release was anticipated by the plant, and even though it caused high measurements of radioactivity over the stack for a short time, it was small and did not last long enough to have a significant off-site impact. Yet the plant staff somehow failed to communicate this to the NRC and the state.

When the make-up tank was vented to a waste gas tank through a leaky header, a plant official called in a helicopter for measurements. The helicopter measured 1200 millirem per hour 130 feet above the stack, directly in the plume. An NRC staff member had calculated that an exposure of 1200 millirem per hour on ground level at the site boundary would correspond to a serious plant situation, i.e., the rupture of the waste gas tank. Communication then became bogged down concerning the difference between the stack and ground level measurement points, and this triggered various and sundry actions. My intent here is not to blame anybody. My point is simply that such communications must be very loud and clear and direct in order to minimize the opportunity for confusion and mistakes.

It is hard to describe the communications problems at TMI because the system had so many loops among so many organizations. The arrival of new people caused a certain amount of fuzziness in the loops involving the company, the state, and the NRC.

As Figure 3 shows, three major operational groups covering plant modifications, radioactive waste management, and technical support were put into action, in addition to the plant operations group. The plant modifications group was created because we recognized the need to move quickly to reinforce certain plant hardware systems, in order to compensate for effects of the accident and to prepare for possible contingencies. For example, because of the large amount of noncondensible gas, we were critically dependent upon forced convection, and thus upon electric power for pumping, for a few days. As most of you may know, very few (if any) light water reactors are designed so on-site emergency power diesel engines can be used to operate the primary coolant pumps. TMI was not an exception, so we were critically dependent upon outside power and transmission lines. We worked to improve the security of the transmission system, and to bring more diesels onto the site. We also acquired additional ventilation systems and filters to back up the plant's existing built-in filter systems.

As I mentioned earlier, we were critically aware of the problem of using the decay heat removal system; this led us to ask questions about the reliability of that system for dealing with water with high concentrations of fission products. We then acted to supply a backup system to provide reliable decay heat removal. We also found that instruments were failing, so we had to look at ways to independently measure water inventory, independently assure that the system was pressurized, etc. These were part of a whole host of plant modifications that we had to carry out to reinforce the plant's safety systems. These tasks generally required engineering and construction work.

The second operational group was charged with managing radioactive wastes. As you know, in effect, we had to turn off all effluent systems. As you can imagine, after these systems are turned off you quickly begin to swim in your own juices. So we had a critical problem of taking care of radioactive wastes, both solid and liquid. The second support group was assigned the tasks of managing tankage, putting in place backup tankage, and generally figuring out how to handle the radioactive waste problem.

The third operational group provided general technical support, backed up by the industry advisory group (IAG) mentioned earlier. The IAG started out with 25 or 30 people, including several key people from the Electric Power Research Institute, almost every reactor supplier, architect engineers, and so forth. During its period of existence, which was about 5 weeks, over 110 people contributed to this group's work. The first IAG contingent arrived on site Saturday, March 31. I told them to begin by examining basic problems separately from the existing plant operations support groups. I told them that we needed supportive people who were not drawn into the day-to-day battle— people who had a broad range of technological expertise, who could step back a bit from the front lines and think about important strategic problems. I gave them four basic tasks. First, they were to identify any pitfalls involved in cooling

At the same time second-hand information was passed along on the direct link between NRC Chairman Hendrie and Pennsylvania Governor Thornburgh. Decisions made at the headquarters level sometimes ignored information flowing among the lower levels.

It is important to keep in mind that in the midst of this confusion the communication links from the accident to the media functioned very, very strongly and effectively in terms of impact on the public. The question we must try to resolve is, Can we make the official communication links strong enough to dominate the short circuits to the media that upset the public and perhaps lead to inappropriate decisions?

Prior to the release of radioactivity on Friday the 30th, I had been lulled into a degree of security by the apparent stability at the plant. From late Wednesday to Thursday night, I was not aware that the continuing operations involved an accumulation of gases that would have to be occasionally transferred, resulting in some off-site exposure. On Friday morning, when we had the release that caused so much concern, I became painfully aware of the significance of the problem. By that time I knew about the generation of hydrogen, its implications for core overheating, and the difficulties of cooling given the presence of a large amount of noncondensible gas. Starting early Friday morning, GPU began to seek further outside help, specifically from people in the nuclear industry, vendors, suppliers, architects, engineers, other utilities, and some of the national laboratories, where I happened to know people. The people who responded to our requests came to be known as the industry advisory group (IAG). The IAG was an important part of the organization that GPU officially put into place in the next few days. Figure 3 shows this organization schematically.

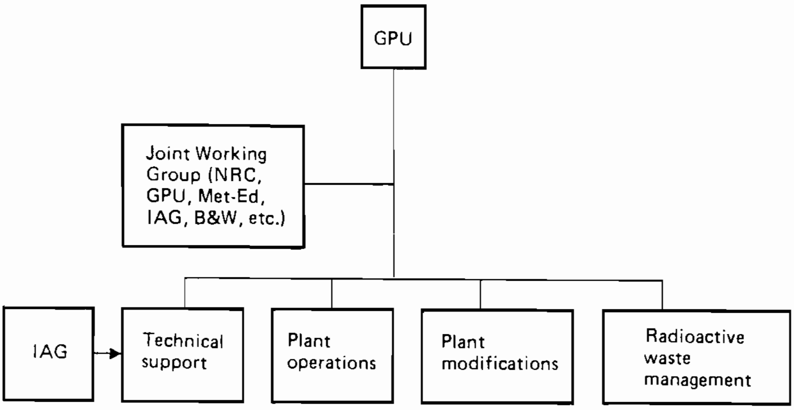

Figure 3. The organization of the TMI accident recovery staff as of April 4th, 1979. (NRC is Nuclear Regulatory Commission, GPU is General Public Utilities, Met-Ed is Metropolitan-Edison, IAG is Industry Advisory Group, and B&W is Babcock and Wilcox.)

the plant; given the large volume of noncondensible gas and a great deal of dissolved gas, the plant was critically dependent upon continuation of forced convection and maintenance of pressure in the system. Second, they were to begin analyzing the degree of damage to the core and the significance of that damage or disarray for reliable core cooling and prevention of further problems. The third task consisted of analyzing future radiation confinement problems, i.e., difficulties with charcoal filters, with released radioactive water, and so forth. Finally, the IAG contingent was to think about necessary plant modifications.

The IAG was deliberately kept separate from the large, integrated organization dedicated to the day-to-day, minute-by-minute management of the plant. It was conceived as a group of scientists and engineers standing off to one side, which could give problems an additional level of analysis, and perhaps extend that analysis further into the future than people involved in day-to-day operations were able to do. In the beginning the IAG suffered some of the same problems, i.e., providing new staff with sufficient knowledge about plant status to permit effective functioning, that the support staff had experienced earlier. Each time additional resources are introduced to provide assistance in such an accident situation, there is a sizable time period when these resources are nothing more than a burden on the plant. Until the new staff members come up to speed they constitute a real problem.

As indicated in Figure 3, we established a joint working group with a task management function, in addition to the operational groups and the IAG. It brought together the heads of each of the other groups and the NRC representative. Responsibility for reviewing important questions of forward planning, important strategic questions, and critical procedural questions came to be vested in this group. It was the mechanism for cross-functional coordination and included NRC views in its consideration of all major actions to be undertaken. I should point out that, while I think our relationship with the NRC was reasonably cordial during the early stages prior to the formalization of the joint working group, there seemed to be a little more standoffishness. The dialogue essentially took the following form, "What are you going to do? Whatever it is, you have to give it to me to approve." I should reiterate that initially I had no problem philosophically with accepting the NRC's role. But when we went over to the organization shown in Figure 3, with an official process for NRC input to the accident management organization, it felt as if somebody had just turned on the lights. All of a sudden, the NRC had direct access and input to what was going on, with the NRC representative reporting back to all of the NRC staff.

One of the most important observations I will make today concerns the tremendous difference in effectiveness between the early modes of organization and the type of organization indicated in Figure 3. The latter structure permitted much more of a common understanding, i.e., a joint definition or development of priorities and working relationships. The difference was almost like night and day. I think we should develop ways to quickly establish an organization that allows all the participants to contribute to the management of the accident as effectively as possible.

The organization indicated in Figure 3 took several days to evolve, then stayed essentially intact until cold shutdown was achieved. I am sure there is nothing fundamental about this organization, but I would like to suggest that its major elements will probably be needed in any organization formed to respond to an accident. One must anticipate that the plant is going to need a tremendous input of technical support, that modifications will have to be made to reinforce safety systems, and that managing radiation wastes will pose a tremendous problem. The industry advisory group was valuable because it provided a degree of assurance to GPU, the NRC, and the public that some of the best minds in the country were working to manage the accident. Finally, the joint working group provided a clear mechanism for coordinating all the groups involved in managing the accident, for focusing their efforts, for establishing priorities, and for getting the job done.

PROCEDURE DEVELOPMENT AND APPROVAL

This review of the accident would not be complete without some consideration of procedure development and approval. I do not ever want to be interpreted as objecting to the need—even under prolonged accident conditions—for some levels of independent review, impartial thinking, and approval. In the event of an emergency this process is just as important as it is during normal operations. 'Normal operations' means that the plant operator is performing tasks, making changes, and establishing procedures in the context of some approved package of technical specifications. In an emergency the plant is suddenly in a state where nobody can identify the appropriate envelope of operations. The only solution is for all those involved to work carefully together to manage the event. However, you must keep in mind that you are not the master in the accident environment. You do not have control of the schedule, the timing of certain actions, and initiatives. You have to look ahead and try to anticipate contingencies and you must always try to arm the plant with a set of fallback positions and procedures. While it is desirable to have independent review and approval of these procedures, the pressure of the accident situation can require that certain procedures be carried out before their approvals have been completed. Since the plant staff has to be in a position to move quickly, the review mechanism has to be treated as somewhat of a back-up system, which identifies current problems, anticipates future problems, etc.

These considerations also apply in the area of plant modifications. Existing requirements for design control, quality control, etc., provide a baseline for decision making, but in an accident situation you have to make critical judgments concerning trade-offs between quality and time. Keeping in mind that you do not have control of the time element, you are faced with questions like "Are we going to have something on time that is reasonably effective, or are we going to insist upon perfection and perhaps have it ready a minute too late, or a day too late, or a year too late?" In an emergency you cannot respond according to your own planning or scheduling or your own logic. Instead you are forced into a reactive mode. The only thing you can do is to try to look ahead and be prepared for those occasions that require a reaction.

CONCLUSION

In closing, I would like to repeat what I see as the three main points of this talk. First, communications are paramount. Strong, well-organized, predetermined lines of communications are needed to form a system capable of providing a cohesive picture of what is going on. This system should keep the public fully aware, in clear terms, of progress in accident management and plant status. Second, the organization of technical support must be clear and well understood, with predetermined roles and modes of interaction for all involved agencies. Approval mechanisms must be carefully maintained, but the possible need for speedy action should be recognized; such action should not be unnecessarily obstructed by slow approval chains. Finally, I cannot overemphasize the magnitude of technical support called for in an accident such as the one at Three Mile Island. The total activity at the site included about 2,000 people two weeks after the accident, and peaked at about 2,800 or 2,900 people a few weeks later. One ends up throwing an almost inconceivable amount of manpower at the problem to try to take care of everything that has to be done.

As I end this presentation, I urge you to read the three reports listed below. All were presented at the American Nuclear Society/Atomic Industrial Forum meeting in San Francisco, November 1979.

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THE NRC'S ON-SITE RESPONSE TO THE THREE MILE ISLAND ACCIDENT

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Following the accident at Three Mile Island on March 28, 1979, a series of notifications and events occurred that precipitated action by the Nuclear Regulatory Commission (NRC) and other state and federal agencies. This paper focuses on the on-site activities performed by the NRC in the following areas:

- — analysis of the event as it was proceeding;
- — projection or anticipation of future events that could have had health and safety impacts;
- — provision of NRC technical resources to assist the licensee to cope with the day-to-day demands of the accident;
- — provision of long-term NRC resources, in support of site activities;
- — facilitation of communication between the NRC and the community affected by the accident and its aftermath.

Significant off-site activities provided by the NRC and other agencies to monitor releases of radioactive effluents and to provide other off-site emergency functions are not examined in this paper. Rather, this discussion is limited to actions taken by the NRC that dealt directly with the assurance and maintenance of facility safety.

The chronology of events and the general accident scenario has been discussed in several documents. The most detailed account is given in a report entitled "Investigation into the March 28, 1979 Three Mile Island Accident by Office of Inspection and Enforcement" (USNRC 1979). The NRC and other authorities were notified about four hours following the accident. Soon thereafter a team of inspectors from the NRC's regional office were dispatched to the site and arrived there at about 10:15 on the morning of March 28. A large technical staff meanwhile assembled in the

NRC's Washington office to monitor activities on-site via direct phone lines, in an attempt to diagnose the situation and provide technical guidance. It gradually became clear that this activity would not succeed because of inadequate communications. Late in the evening of March 28 I was asked to assemble a team of two reactor systems specialists, two radiological specialists, and two instrument and control specialists, to proceed to the site early the next morning. By that time the NRC already had 11 people on site, as well as a mobile laboratory van for the analysis of the radiation content of environmental samples. In addition, teams provided by the Department of Energy were performing some environmental monitoring and aerial surveys.

When our team arrived at the site just before noon on Thursday, March 29, we found a lull in activity because radiation readings at or near the plant were not alarming and no radioiodine had been detected. The reactor system itself seemed to be performing in a stable manner, except for a "soft system," which implied the presence of noncondensable gases in the primary system. Plant operators were also unable to stop periodic discharges of noble gases. The full significance of the situation did not become clear until later, when analysis of the primary coolant sample showed significant core damage, when the hydrogen bubble problem became apparent, when the hydrogen burn in the reactor building was recognized, and when several more significant releases of radioactivity occurred.

Even on Thursday, a relatively quiet time, the communication capacity at the site was far overtaxed. In our role as lead staff trying to perform on-site analysis, we were severely hampered both by lack of communication and the inability of utility personnel to provide cogent information on system parameters.

By late Friday afternoon, when the severity of the situation was quite evident, over 80 NRC staff members were on site. It then became a problem to decide how staff members should be allocated. It was apparent that the licensee needed technical assistance in four vital areas:

(1) Diagnosing the current plant situation and projecting the operational maneuvers needed to preclude further reductions in plant safety;
(2) Developing procedures quickly to instruct plant operators on their course of action, as off-normal techniques were required for dispersing the hydrogen bubble and for performing other necessary operations;
(3) Coping with significant health physics and radwaste problems;
(4) Considering and planning for procedural and equipment contingencies—for example, planning a contingency method for providing additional core cooling, by off-normal means if needed to assure long-term safety, and planning for the installation of additional systems.

To provide help in these areas, the NRC technical staff was divided into two groups that operated around the clock in two

12-hour shifts. Some of the staff was responsible for assisting the utility in preparing procedures and in resolving health physics and radwaste problems. Since these activities could at times conflict with the facility license as it existed at the time of the accident, the NRC had to give explicit written approval for the implementation of all new or revised procedures. This policy was instituted to ensure that the licensee would not violate its facility specifications and, more importantly, to provide a technical quality assurance check on the effectiveness and safety of the proposed activity. In many instances this policy required that the TMI staff consult the NRC on each step of the operation, so the NRC could independently monitor the operation and system's parameters. Because the utility did not have enough staff familiar with the plant to write effective procedures, this policy proved very worthwhile.

Other NRC staff members had the task of independently assessing minute-to-minute operations, looking for trends, and searching for clues that would indicate incipient problems. This task involved monitoring operational parameters, analyzing trends, and developing criteria to establish when alternate courses of action might be taken. Another group of NRC representatives, in conjunction with an industry advisory group assembled on site, assisted in planning for activities that would cope with foreseeable contingencies and provide for a long-term safe shutdown. At this time the NRC directed most of its response activity from the site itself, although it utilized large resources and technical talent from the Washington office, NRC regional offices, and NRC contractors.

Finally, the NRC provided support activities to obtain services, equipment, or supplies that otherwise would have been difficult for the utility to acquire quickly or that perhaps would even have been unavailable to industry. In the early days of the accident many demands arose for equipment and supplies. These demands were generally filled through NRC contacts at various labs dealing with nuclear matters, and then shipped on an expedited basis with the aid of US Air Force facilities. For example, thousands of pounds of lead for shielding were flown to the site on a priority basis. Several robots were made available in case they were needed for taking highly radioactive samples or performing other activities in environments hostile to humans. (They were not used, however.) National laboratory facilities were also made available for the quick analysis of samples to determine the extent of radioactive releases.

For a month to six weeks following the accident, all the above activities constituted important responses. By the end of this period most contingency measures had been developed, the reactor itself was in a safe shutdown configuration, and the general extent of contamination was reasonably well known. The remaining tasks included development of a long-term decontamination and cleanup program and maintenance of the facility in a safe configuration. In this context the NRC has established an on-site group responsible for long-term operations. In keeping with its tasks, this group is composed primarily of systems engineers, radwaste engineers, and health physicists, about 15 professionals in all. They are currently responsible for the review and approval of all systems designs and modifications, as well as operational plans and procedures for the recovery process. They must also deal with the local public and press—a job that has proven very important as a result of the public concerns generated by the accident.

The long-term operations group is also involved in the preparation of environmental analyses that are required for evaluating various approaches to cleaning up the facilities and for dealing with the waste generated. We anticipate that this level of participation will continue for at least three to four years—perhaps even longer if portions of the cleanup process, such as removal of the damaged core, take significantly more time than anticipated.

Recently the NRC opened an office in Middletown, Pennsylvania, in an effort to improve public access to the NRC and to documents of public interest. We consider convenient public access to this information important both from a public relations viewpoint and as a means of helping to dispel public anxiety about the accident and its aftermath. This is the first office of this type that the NRC has opened. The anxiety and concern still expressed by the local population over such issues as the cleanup process and the possible future start-up of either Unit 1 or Unit 2 requires that the NRC maintain close community links.

SUMMARY

Early evaluation of the Three Mile Island accident pointed to a need for significant technical and logistic resources that the utility alone could not supply. It is unlikely that any utility in the US could have provided all these resources. During the accident it became clear that the NRC would have to go beyond its traditional licensing and inspection role and assume more of a participatory role to meet the needs of public health and safety. The need for NRC staff to work closely with the licensee as technical consultants and to be involved in each step of the post-accident facility operation has provided the rationale for some of the requirements now being examined in the course of the NRC's "Lessons Learned" activities and ongoing investigations. NRC's involvement in the accident pointed out that more planning and a significantly higher level of resources must be developed by both the nuclear industry and the NRC for utilization in the unlikely event of another serious nuclear accident.

REFERENCE

United States Nuclear Regulatory Commission. 1979. Investigation into the March 28, 1979 Three Mile Island Accident by Office of Inspection and Enforcement. USNRC Report NUREG-0600. Washington, D.C.

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EMERGENCY PREPAREDNESS AND RESPONSE IN THE COMMONWEALTH OF PENNSYLVANIA—THE THREE MILE ISLAND INCIDENT

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INTRODUCTION

This paper addresses the emergency response mechanism and legal basis in effect in the Commonwealth of Pennsylvania at the time of the Three Mile Island incident. It reviews the sequence of events as they directly affected the Pennsylvania Emergency Management Agency and examines the method used by the Agency to discharge its responsibilities. Finally, the paper lists some of the lessons learned from the Three Mile Island experience.

I do not wish to take sides in the debate about how much we need nuclear energy or how easily we can do without it. It is sufficient to say that many knowledgeable people argue that this country's use of nuclear power to meet a small portion of its energy needs cannot be eliminated without very serious and damaging economic consequences. During the past year, small reductions in oil imports have reminded us of this fact. Thus it is reasonable to assume that we will continue to utilize nuclear energy and that we may become more dependent upon it in the future. Logic dictates that if we must have nuclear power, then we should try to minimize its risks, and to be prepared to meet the consequences, should all else fail.

PENNSYLVANIA EMERGENCY MANAGEMENT AGENCY

The Pennsylvania Emergency Management Agency functions as a semi-independent Agency under the office of the Governor. Through this organization the Governor exercises his emergency responsibility for the protection of the health, safety, and well-being of Commonwealth citizens faced with man-made or natural disasters or enemy attack.

The Pennsylvania legislation governing emergency preparedness and response is patterned after the model act developed by the Council of State Governments. Many states have used the model act as a guide, modifying it to meet special needs and to accommodate individual organizational arrangements. The Pennsylvania legislation calls for a Council and prescribes its membership. This Council, chaired by the Lieutenant Governor, is responsible for both developing overall policy and providing guidance to the Pennsylvania Emergency Management Agency. The Council membership includes the Governor, Lieutenant Governor, four members of the State Senate and House and ten Secretaries of Departments having major emergency responsibilities.

The law prohibits the Pennsylvania Emergency Management Agency from duplicating the functions of any other State agency. Consequently, the tasks of the Agency are to maintain a close liaison with all State agencies, to determine gaps in missions and roles, and to develop integrated plans to assure continuing identification of State resources and the prompt assignment of these resources to reduce the vulnerability of people involved in emergencies. The Emergency Operations Center of the Pennsylvania Emergency Management Agency and its three Area Centers are augmented, during times of disaster, with representatives from other State agencies that have an emergency role. These representatives have the authority to perform on behalf of their respective agencies and to commit resources in accordance with predetermined procedures.

The day-to-day role of the Pennsylvania Emergency Management Agency involves analyzing problem areas and vulnerabilities, planning for possible emergencies, and training staff and County Coordinators. The Agency conducts quarterly exercises with response team members to assure the maintenance of understanding and knowledge about the Agency's Standing Operating Procedures.

The Pennsylvania Emergency Management Agency Emergency Operations Center is located in an underground, protected facility in the Capitol complex in Harrisburg. Three Area underground and protected facilities are strategically located to extend the Agency's coordination and management role. The Harrisburg Center communicates with its three Area Centers by telephone, radio, and a dedicated teletypewriter system.

Each political subdivision of Pennsylvania is required by law to have an emergency management organization. (The Commonwealth has a total of 2,636 political subdivisions—67 counties, 52 cities, 966 boroughs/towns, and 1,551 townships.) Each Emergency Management Coordinator is appointed by the Governor, on the basis of recommendations from the elected officials of the political subdivision. Information flows from boroughs, towns, and cities to the county level, then to Area, and finally to State levels, and vice versa.

There are four fixed nuclear sites within the Commonwealth of Pennsylvania. Two additional sites are under construction and scheduled to begin operations in 1982 (Berwick) and 1983 (Limerick).

In the past the State Bureau of Radiation Protection, Department of Environmental Resources, had responsibility for planning state response to emergencies at fixed nuclear sites. In 1975 the Bureau of Radiation Protection forwarded a plan governing nuclear emergencies to the Nuclear Regulatory Commission, but failed to receive concurrence for it. The plan was revised in September 1977, but not formally submitted to the Nuclear Regulatory Commission. On the basis of the 1977 plan the Pennsylvania Emergency Management Agency (which had assumed responsibility for emergency planning) added a section on "Nuclear Incidents, Fixed Facility" to the Pennsylvania Disaster Operations Plan, a document which provided guidance to State agencies and political subdivisions. All planning was based upon a five-mile protective action distance around each site. As of March 1979 county plans in support of the State Disaster Operations Plan were "in place" and had been reviewed and updated during the summer and fall of 1978.

THE SEQUENCE OF EVENTS

At 7:02 a.m., on March 28, 1979, the Pennsylvania Emergency Management Agency watch officer received a telephone notification from the Three Mile Island Plant Supervisor that Three Mile Island had declared a site emergency. In accordance with the Pennsylvania Emergency Management Agency Standing Operating Procedure (SOP), the watch officer proceeded to notify, in order of priority, the following:

(1) Duty Officer, Bureau of Radiation Protection, Department of Environmental Resources
(2) Dauphin County (host county)
(3) York County (within 5 miles of Three Mile Island)
(4) Lancaster County (within 5 miles of Three Mile Island)
(5) Pennsylvania Emergency Management Agency Operations Officer

At 7:20 a.m. the Duty Officer at the Bureau of Radiation Protection advised the Pennsylvania Emergency Management Agency watch officer that he had concluded after discussions with personnel at Three Mile Island that there were no off-site consequences. The watch officer, in turn, passed this information to the affected counties.

In the meantime, the Pennsylvania Emergency Management Agency Operations Officer arrived at the Emergency Operations Center and relayed the Duty Officer's report to the Director of the Pennsylvania Emergency Management Agency. The Operations Officer, together with early staff arrivals, relieved the watch officer. Subsequent actions were handled through the Pennsylvania Emergency Management Agency Emergency Operations Center.

At 7:35 a.m. the Three Mile Island Plant Supervisor notified the Pennsylvania Emergency Management Agency Operations Officer that conditions were worsening and that a general emergency had been declared. The Plant Supervisor recommended that the

Pennsylvania Emergency Management Agency be prepared to evacuate Brunner Island and the Borough of Goldsboro. He reported that a radiation release to the atmosphere had been and was still occurring, and that winds were in the direction of 30°. The Pennsylvania Emergency Management Agency Operations Officer passed this information to the Bureau of Radiation Protection, alerted York County to be prepared for evacuation of Brunner Island and the Borough of Goldsboro, and advised Dauphin and Lancaster Counties of the situation. The Director of the Pennsylvania Emergency Management Agency notified the Governor and Lieutenant Governor of the reported conditions. Shortly thereafter, the Bureau of Radiation Protection advised that the release had been halted and that no evacuation was required.

It was subsequently learned that the sequence of events which ultimately led to the emergency notifications had actually begun around 4:00 a.m. With this exception, all reporting and notification procedures conformed to established procedures, and all telephone circuits were functioning.

On the 28th and 29th of March, the Pennsylvania Emergency Management Agency and the three affected counties made a considerable effort to flesh out existing plans. As a precaution, the Pennsylvania Emergency Management Agency maintained a scaled-down 24-hour operational capability in its Emergency Operations Center. Reports received on the 28th and 29th of March, although frequently conflicting, generally reflected progress towards a cold shutdown of the reactor. Nuclear Regulatory Commission representatives repeatedly acknowledged that Metropolitan Edison personnel were doing a superb job and were demonstrating dedication and professionalism. National news media were seeking stories away from the scene relating to nuclear safety and several articles treated speculative events. The film "China Syndrome" was showing in several area theaters.

At 8:40 a.m., on the 30th of March ("Black Friday"), the Pennsylvania Emergency Management Agency received two simultaneous telephone messages from Three Mile Island. Three Mile Island personnel reported a general emergency condition due to a radiation reading of some 1200 mR/hr. They informed the Agency that the facility was preparing to evacuate nonessential personnel and recommended that the Pennsylvania Emergency Management Agency be prepared to evacuate downwind areas. This information triggered an alert to the affected counties and the initiation of the full activation of the State Emergency Operations Center.

At 9:15 a.m., the Bethesda, Maryland Office of the Nuclear Regulatory Commission advised the Pennsylvania Emergency Management Agency that it also recommended a downwind evacuation of the Three Mile Island facility within a 10-mile range. The Bethesda Office reported that this recommendation had the support of senior personnel at the Nuclear Regulatory Commission.

Subsequent discussions between the Bureau of Radiation Protection and Three Mile Island personnel and between Governor Thornburgh and the Commissioner of the Nuclear Regulatory Commission determined that existing conditions did not warrant such a radical step. Instead the Governor issued an advisory at approximately 10:00 a.m., March 30, for all people within ten miles of the Three Mile Island facility to remain indoors until further notice. This was followed by a further advisory shortly after noon for all pregnant women and preschool-aged children to evacuate the area within five miles of the facility.

Selected units of the Pennsylvania National Guard were placed on a "white alert." They were directed to be prepared to support each county at risk with one battalion and to provide a backup battalion in support of each committed battalion. The Pennsylvania State Police were prepared to bring maximum force into the area as well. Both the National Guard and the State Police were ordered to be prepared to assist with any evacuation and to provide traffic control and security for any area evacuated. For the most part, the local police, fire, and emergency medical forces in the area at risk were fully activated and in an advanced readiness posture.

PROBLEMS AND EXPERIENCES

Following the Governor's advisory for partial evacuation, a number of people commenced an orderly, voluntary movement out of the area. Commercial banks and savings institutions were immediately besieged with people wishing to withdraw funds. Hospitals began to reduce their patient loads by discharging some patients and rescheduling elective surgery cases. During this period, the Pennsylvania State Police aerial traffic observer reported no abnormal traffic patterns. Analysts subsequently determined that reportable traffic accidents/incidents were approximately 25% lower in counties in the affected area during the Three Mile Island incident, compared to a similar period prior to and a corresponding period after the incident.

Immediately following the Governor's 10 a.m. 'take cover' advisory, a telephone overload occurred. For approximately three hours, 30- to 40-minute time delays were experienced throughout the Harrisburg exchange. Both the news media and public inquiries totally saturated the 100-plus lines servicing the Pennsylvania Emergency Management Agency Emergency Operations Center.

As a result of the Nuclear Regulatory Commission's recommendation to evacuate the area within a radius of ten miles, the Pennsylvania Emergency Management Agency, the Department of Transportation, and the Pennsylvania State Police made a hasty traffic analysis and reassigned major route priorities to the risk counties. Personnel from the Pennsylvania Emergency Management Agency and the Defense Civil Preparedness Agency were assigned to the risk counties to assist in the planning effort. Direct telephone lines between the Pennsylvania Emergency Management Agency and the affected risk counties were installed, and the Defense Civil Preparedness Agency voluntarily put a radio system into operation linking the Pennsylvania Emergency Management Agency and the counties at risk.

At approximately 8:30 a.m., on Friday, March 30, the Nuclear Regulatory Commission advised that it would be prudent to develop plans for an evacuation of the area within a radius of 20 miles from the Three Mile Island facility. This increased the counties at risk from three to six and enlarged the population at risk from 30,000 to 750,000. Neither the existing five-mile county plans nor the preliminary plans for a ten-mile evacuation were compatible with the problems posed by a 20-mile evacuation scenario. For all practical purposes, NRC's advice cancelled all earlier plans and evacuation guidance and set a new course of action in motion. The pace of planning took on an increased degree of urgency. In addition to the six counties at risk, 21 additional counties were alerted for an evacuation hosting role.

In the course of the new evacuation planning, a considerable number of new problems surfaced. These included

- — movement of seriously ill patients, patients on life support systems, and newborn babies;
- — care and disposition of pets and livestock;
- — degradation in the availability of medical personnel and volunteer forces;
- — leadtime requirements of business and industry;
- — security of prisoners and other institutionalized persons;
- — responsibility for associated costs;
- — stockpiling and issuance of radioprotective drugs;
- — movement of the seat of government;
- — sounding of sirens both inadvertently and purposely.

Handling of rumors and misquotes in the news media proved to be extremely time-consuming. Governor Thornburgh and Harold Denton, the Nuclear Regulatory senior official on site, retained considerable credibility as sources of information. Other Federal agency and Metropolitan Edison spokespersons received little acknowledgement. A large number of people reported that they didn't believe anyone.

The experiences of the Pennsylvania Emergency Management Agency during the Three Mile Island incident were in many respects similar to those encountered in previous natural disaster events —differing primarily in degree or magnitude. Perhaps the single exception is that the perception of a danger (aura of mystery) that cannot be seen, felt, smelled, or tasted resulted in an attitude not generally shared in other emergency responses. Antinuclear and/or concerned individuals and groups were extremely outspoken on this point. The Pennsylvania Emergency Management Agency had to convey an attitude of restraint and caution during an incident that threatened to be catastrophic for the general public.

The following are some of the lessons learned from the Three Mile Island incident:

- We can no longer take for granted that nuclear power plants are safe. Our planning should not treat an accident only as an extremely remote possibility.

- We need to obtain radioprotective drugs and plan for their dissemination and use.
- We need to focus more attention on the handling of people under special care in homes, hospitals, and institutions.
- We need to improve the level of information concerning nuclear radiation in all segments of the population.
- We need a fully integrated and adequately redundant in-place communications system.
- We must do a better job of bringing county and local government officials into the decision-making process.
- We must recognize emergency management's dependency upon volunteers and volunteer forces and we must understand that they may not always be available.
- We must improve our capacity for handling the news media and assuring their continuous access to coherent sources of information.
- We must develop a more formal system for tests and exercises.
- Our planning effort must assure total integration between all levels of government.
- We need, on the national level, a uniform emergency nuclear incident classification system.
- We need to standardize procedures for the systematic study of the social, economic, and health aspects of an incident.
- We need to improve our record keeping.
- And, finally, we urgently need to seek solutions to the problems associated with fixed nuclear power facilities—not on the basis of the emotionally-charged rhetoric of the moment, but using dispassionate, reasoned analysis.

III. EMERGENCY PLANNING AND PREPAREDNESS: INTERNATIONAL PERSPECTIVES

This Section contains discussions of emergency planning and preparedness in six different countries—countries that have been fortunate enough not to have experienced an accident like TMI. Principles underlying the criteria for dose-based countermeasure guidelines are presented, as well as zones as bases for plans, and criteria for accident classification. Attention is also given to the content of accident management plans, including the division of responsibility among government and private agencies, measures for information management, and strategies for maintaining preparedness.

The Section provides a broad survey of international approaches to the problems of emergency planning and preparedness. It is the task of the reader to ask how well the plans and organizations described in the papers address the problems and issues raised by the TMI accident.

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NUCLEAR REACTOR ACCIDENT PREVENTION AND MANAGEMENT

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INTRODUCTION

This paper presents views on the essential aspects of the actions that must be taken to prevent and—if these actions are inadequate—to manage nuclear reactor accidents. These views are based upon the perspective of the Office of Inspection and Enforcement within the Nuclear Regulatory Commission. It is presumed that design review and accident analysis evaluation have been conducted or are in progress, using the most current criteria.

Accepting this premise, the individuals charged with the inspection and enforcement of regulatory requirements base many of their activities on two further assumptions:

- Existing regulatory requirements have a sound basis for assuring public health and safety.
- Existing regulatory requirements are not adequate for eliminating every possible threat to public health and safety.

The first point leads the Office of Inspection and Enforcement to implement programs designed to assure that licensees adhere to regulatory requirements and, when adherence is not demonstrated, to set corrective action into motion. Such corrective action must not only reestablish compliance with requirements, but must also be sufficiently comprehensive to preclude recurrence of the violation.

The second point gives recognition to the evolutionary nature of the regulatory process; the development of regulatory requirements is dependent upon an effective feedback network that accounts for lessons learned from actual operating events and facility incidents. This feedback system provides the technical basis for refining and updating the regulatory requirements imposed on a given licensee.

These perspectives serve as the basis for the observations that follow. It must be stressed that the actions discussed in this paper presuppose that design review, safety evaluation, and safety research are being aggressively pursued. Otherwise the climate would be unsatisfactory for accident prevention and, should the occasion arise, accident management.

ACCIDENT PREVENTION

The prevention of accidents at nuclear reactors requires the rigorous application of quality measures to achieve two fundamental goals:

- To assure that the condition of plant safety systems is such that they can perform their intended function when required.
- To assure that all activities conducted at the facility are critically reviewed to identify system, component, organizational, or procedural deficiencies and to permit prompt and appropriate corrective action.

From an inspection and enforcement standpoint, these goals should be applied to at least the following functional areas:

- Surveillance and system testing;
- Maintenance and modification activities;
- Evaluation of the technical adequacy of procedurally controlled and other activities;
- Reviews of events.

Each of these functional areas will be discussed in further detail below, accompanied by observations on the sharing of the responsibility for their implementation.

System Testing

The testing of plant systems to assure functional capability requires that an appropriate test be conducted during the preoperational or start-up phase. This test must truly demonstrate that the system conforms to design parameters. The successful completion of the test then serves as a basis for the development of abridged surveillance tests. Such surveillance tests are utilized throughout plant life as continuing indicators of system capability.

Since the safety-related systems being tested serve either as control systems to prevent accidents or as mitigating systems to limit accident consequences, it is necessary to vigorously pursue and adhere to the testing programs. The procedures for conducting system tests must be developed with a full recognition of the control (or post-accident) bases underlying the system design. We continue to find instances in which a test utilizes acceptance criteria which do not appropriately reflect the difference between test conditions and a system's functional requirements. For example, the ventilation system for the annular space between a freestanding reactor containment and the shield building typically has the functional requirement to establish a negative pressure within a certain elapsed time following a Loss of Coolant Accident (LOCA). The acceptance criteria for the system test must account for the absence of the LOCA thermal loads to the annular space. Here it is necessary to establish appropriate, shorter-time-frame criteria to test system performance.

Similarly, the results of such system tests must be reviewed most critically. The review should assure that such conditions as marginal conformance to acceptance criteria are not indicative of a long-term inability to assure system functional capability.

After the initial demonstration of system capability, it is necessary to establish and then vigorously follow the surveillance testing program to be used during the lifetime of the plant. The tests must be meaningful, and the results must be critically evaluated. Since unnecessary challenges to safety systems should be avoided, it is often necessary to conduct surveillance testing in a piecemeal fashion so as not to adversely affect plant operation. However, such piecemeal tests must provide for enough overlap of subsystem tests to assure that they are meaningful. Special quality measures must be established for this purpose. Several instances of such inadequate overlap of subsystem tests have occurred; as a result entire safety functions have not been tested for prolonged periods. In some cases, the protective mechanism had been improperly installed, and the problem was not discovered due to the lack of adequate testing. Surveillance programs are needed to overcome such deficiencies. They must be appropriately implemented to assure that safety systems have the functional capability to perform in preventing or mitigating nuclear reactor accidents.

Modification and Maintenance Activities

The testing activities described in the preceding section are designed to confirm the functional operability of systems; but it is clear that such testing (as well as other circumstances) often identifies the need for corrective maintenance or system modification. Such corrective or modification activities must be carried out using the strictest quality measures in order to assure the reestablishment of the operability of the affected system.

As explained above, the technical basis for the surveillance test is a previous successful system test, including detailed testing of pump run-in, valve stroke times, electrical support system performance, and so forth. Maintenance or modification activities disrupt the technical basis for the surveillance test. For this reason post-maintenance or modification testing must adequately demonstrate that the system has been returned to a state of readiness appropriate for surveillance testing. The surveillance test alone does not serve this function.

For example, the replacement of seals on all low pressure injection pumps at a plant provides the potential for a common mode failure problem. If the pumps are required to operate for 30 days following a major accident, the standard 15-minute pump surveillance test does not assure that the new seals were correctly installed. Only an appropriate post-maintenance/modification testing program can provide this assurance.

Technical Adequacy Evaluations

The technical adequacy of all activities conducted at a site are crucial to the prevention, if not the mitigation, of nuclear reactor accidents. We have already mentioned the need for acceptance criteria for technical adequacy of system, surveillance, and post-maintenance tests. Other operational activities that deserve vigorous evaluation for technical adequacy include

- — all procedural controls, including routine operations, emergency operations, surveillance, maintenance, and radiological activities;
- — all staff training activities, including activities that are considered to fall under the skill-of-the-craft of various staff members.

The evaluation program must take the form of a dynamic program conducted throughout the life of a plant. The present regulatory requirements call for licensee plant review groups, corporate review groups, regular audits of activities, and, more recently, organizations assigned the task of assessing operational experiences. But clearly the act of institutionalizing these mechanisms does not assure that they will be vigorously pursued. Only through the careful selection of personnel—with regard to their commitment to safe operation, as well as their background and specific training—will these mechanisms serve their intended purpose. Their purpose should be to

- — review every new safety-related control or activity undertaken;
- — re-review existing controls or activities in light of new information or operating experience;
- — re-review controls or activities in light of changing regulatory requirements.

These measures will not be sufficient to prevent accidents if they are applied primarily to satisfy the requirements of the regulatory agency. Rather, they must be applied within the context of a mission of safety. For example, emergency procedures should be "walked through" by experienced personnel to try to identify every procedural weakness prior to implementation. Similarly, whenever a given procedure needs to be implemented in a real event, it is necessary to reevaluate its effectiveness in controlling the evolution of the accident. The lessons learned from the evaluation of the specific procedure must then be applied to every other emergency procedure subject to similar faults. This recommendation does not aim to constantly increase the number of procedures and controls, but rather to continually test and improve the effectiveness of technical adequacy evaluations.

Reviews of Events

Reviews of events, as a means of preventing accidents, are inextricably tied to the issue of technical adequacy evaluations. The critical review of events is a primary procedure for identifying and subsequently resolving system, component, or operational deficiencies. Examples of identification of such deficiencies from event reviews are numerous. The following three are particularly relevant.

- A plant trip, initiated as part of a start-up test program, resulted in a hanger anchor bolt failure that led to identification of industry-wide deficiencies in anchor bolt installations;
- A review of reportable occurrences identified industry-wide deficiencies in plant seismic analyses of the as-built configurations of the plants;
- A review of reportable occurrences identified deficiencies in safety-related relay manufacturing controls.

These examples show the benefits of reviews of off-normal events for plant safety. A case can also be made for critically reviewing normal operational events to assure that transient analyses are correct or, conversely, to identify when the plant or some subsystem is exhibiting characteristics that were not predicted.

As a result of this mechanism, each operating plant becomes, in essence, an experimental laboratory; the lessons learned from every facet of plant operation can help to improve general plant performance and safety. Of course, each issue raised in such reviews of events may well lead to extended plant shutdowns and/or major capital expenditures by plant operators. However, the feedback needed to improve plant safety and thereby prevent reactor accidents will occur only through such actions on the part of the utilities and the regulatory agencies.

The results of reviews performed to date support the earlier contention that the regulatory requirements applicable to nuclear plants are not sufficient to assure public health and safety. The evolutionary process of review, identification, and resolution leads to the refinement of regulatory requirements—often to the dismay of the industry—and contributes to enhanced public safety.

Clearly, the greatest benefit of critically reviewing operational events and transients can be derived from scutiny of serious nuclear incidents. Detailed reviews of the accident at Three Mile Island Unit 2 on March, 28, 1979, for example, have prompted profound changes in approaches to accident prevention, both on the part of plant managers and the regulatory agency. Further changes will be instituted in the future, as well they should, to assure the full use of the lessons learned from the accident. Long-term changes in approaches to accident prevention are reflected in

- the long-term recommendations of the Lessons Learned Task Force (USNRC, October 1979);
- the recommendations of the NRC Special Inquiry into Three Mile Island (USNRC Special Inquiry Group, January 1980);
- the recommendations of the President's Commission on the Accident at Three Mile Island (President's Commission, October 1979);
- the tasks identified by the NRC Action Plan currently under development (USNRC, February 1980).

The bibliography at the conclusion of this chapter provides the sources of more detailed information about these recommendations and tasks.

Despite the scope of the above activities, the value of carrying out further reviews of plant operations remains undiminished. This view is confirmed by the NRC decision to establish the Office of Analysis and Evaluation. As well, the nuclear industry has established the Institute for Nuclear Power Operations and the Nuclear Safety Analysis Center. In addition to these large organizations, the NRC Office of Inspection and Enforcement Headquarters and NRC regional offices are taking steps to enhance their capability to critically review operational events. Licensee operating organizations are undertaking similar activities. Clearly, it is inappropriate to assume that the accident at Three Mile Island revealed all the lessons we have to learn.

Responsibilities

Facility operating organizations and the responsible regulatory agencies share a parallel responsibility to achieve the goals discussed above. A facility operating organization must apply test, maintenance, evaluation, and review measures to its own facility and must then inform the regulatory agency of its findings. In the US the NRC is currently taking steps to further clarify the kinds of issues about which it requires prompt and detailed information. However, it is difficult to impart to regulatory requirements the totality of coverage needed to address all issues. For this reason the utilities must follow the "spirit" as well as the "letter" of such regulations. Such a recognition will substantially enhance plant safety.

The regulatory agency in turn has the duty to refine and implement its inspection and review processes. It must assure the public that deficiencies are being identified, evaluated, and resolved. Moreover, it must aggressively pursue the identification and resolution in all facilities of deficient conditions discovered in any one facility. It is clear that the efforts of the NRC to fulfill this obligation have increased substantially since the accident at Three Mile Island. The following table shows the measures taken by the Office of Inspection and Enforcement. A similar tabulation could be made for generic letters and orders issued by the Office of Nuclear Reactor Regulation.

While some of the information dissemination and recommendations for action shown in Table 1 were directly related to TMI,

Table 1. Measures of actions taken by the NRC Office of Inspection and Enforcement to identify and resolve deficient conditions, before and after the Three Mile Island accident.

	9 months prior to TMI	9 months subsequent to TMI
Bulletins issued (requiring licensee action)	12	30
Circulars issued (recommending action)	12	20
Information Notices issued (providing information)	8[a]	29

[a] Information Notice System initiated on February 2, 1979.

the majority were not. The step-up in activity after the accident reflects the agency's recognition that the TMI accident, as it evolved, may well have been prevented, if such measures had been pursued more aggressively earlier.

ACCIDENT MANAGEMENT

Because other papers in this volume discuss emergency planning and preparedness on the part of utilities, local civilian authorities, the state, and the federal sector, it would be redundant to discuss these issues here. Rather, this paper examines the operational aspects of accident management at plants, as this applies to facility staff and the regulatory agency.

A basic requirement in accident management is that the immediate participants have a thorough understanding of the facility design and operational characteristics. The operating staff of the plant has this knowledge, and it is clearly their immediate responsibility to deal with evolving accident conditions. However, the shift operating staff are responsible for both plant safety and continued plant operation; for this reason it is advantageous to have a technically astute advisor immediately available to provide insight about the significance of plant conditions. The recently mandated shift technical advisor (STA) is supposed to provide this service, but the full scope of the STA's responsibilities still needs to be clarified. Several important issues have yet to be resolved—for instance, the consequences stemming from the failure (inadvertant or by choice) of plant staff to follow the advice of the STA.

Several inquiries have revealed that the philosophy of accident management was too limited in scope in the case of TMI. Prior to TMI, it was assumed that accidents would "run their course" in a very rapid time sequence and thus that the utility and the regulatory agencies would assemble emergency staff for post-accident recovery, not accident management. The TMI experience showed the error of this view; as well, TMI raised the new issue of the adequacy, on a real time basis, of communications with all the organizations needed to help manage the accident.

Here reference is made to the broadest meaning of the term "communication", i.e., the exchange of information. The protracted nature of the Three Mile Island accident demonstrated the need for a viable information and technical support network. To meet these needs several new requirements have been established for nuclear power plants since the TMI accident:

- the provision of a technical support center at each facility to provide engineering support during an accident;
- the provision of dedicated telephone lines between the facility and the regulatory agency;
- the expansion of the resident inspector program to place at least two resident inspectors at every site to provide an on-site interface between plant conditions and the information needs of the regulatory agency.

Investigations of the TMI accident showed that the effectiveness of both the utility and the regulatory agency was partially dependent on the information flow between and within each group. Many of the problems associated with the orderly flow and analysis of information on plant conditions during an accident remain to be resolved. Further studies are underway to determine the practicality of monitoring critical plant parameters at the operations center of the NRC, either on a continuous basis, or on a selective basis after the start of an incident.

SUMMARY

The prevention of nuclear reactor accidents requires a continuing critical application of quality measures for testing safety-related systems, for maintenance and modification of safety-related systems, and for technical adequacy evaluations of all plant activities. Reviews of operational events are also needed to assure that the analyses performed for the plant are valid or that systems are performing in accordance with their design. Within this framework, it should be possible to determine the corrective actions necessary to assure a continuing low probability of reactor accidents.

Should these measures prove inadequate, and a reactor accident occurs, actions have been initiated by both licensees and the NRC to provide for the management of an accident that evolves slowly. Both the licensee and the NRC may need to take further actions. The necessity for effective communications during such a period is evident; whether the steps taken to date are adequate remains to be evaluated.

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EMERGENCY RESPONSE TO A NUCLEAR FACILITY ACCIDENT: PREPLANNING AND PREPAREDNESS BY OFF-SITE ORGANIZATIONS

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INTRODUCTION

In the past quarter century of commercial nuclear power development, with its attendant supporting fuel cycle facilities, the record of nuclear safety has been excellent in general terms. But it has not been flawless and we have received some serious warnings. The 'defense-in-depth' concept, i.e., multiple barriers between radioactive materials and man and the environs, has governed the practical uses of nuclear energy and materials. These multiple barriers have been breached in some of the accidents that have occurred in nuclear industry—resulting in radiological exposures to man and contamination of the environment. Fortunately, in most of these accidents, off-site radiological consequences were relatively minimal, but the potential for more serious consequences existed.

The last bastion in the 'defense-in-depth' concept is a proper and effective emergency planning and preparedness program to support nuclear facilities. Generally speaking, radiological emergency response planning, and attendant preparedness as it relates to nuclear facilities, has never had high visibility within the nuclear industry or within governments. Historically, the numbers of personnel, resources, and funds devoted to it have been relatively small, as a percentage of the total resources used to construct, operate, and maintain nuclear facilities.

There are a variety of reasons for this state of affairs. First, relatively low priority was assigned to emergency planning and preparedness; this has at its roots the individual, political, societal, governmental, and industrial perceptions of a high-technology human endeavor. Second, two long-cherished notions contributed to this low priority, namely, that nuclear facilities were designed, constructed, and operated with such integrity that *the chances of a serious accident occurring were extremely remote*, and that because of the integrity of design, construction, and operation *any perceived accident would have little effect in terms of off-site radiological consequences.*

Serious rethinking of the "chances" or "probabilities" of accidents has taken place. It has been realized that basing emergency planning and preparedness solely on "probabilities" may not be entirely valid. The notion that little would happen in terms of off-site consequences in the event of an accident is to some measure still supported by the integrity of retention provided by the nuclear facilities themselves. One cannot say too much with respect to the human role in the control of these facilities when accidents have occurred, except to note that some correct moves were made, but at the same time, many incorrect moves were made as well. The point is that a degree of good fortune in some of the nuclear facility accidents led either to an absence of or to relatively minimal radiological consequences to man and his environment.

A great deal of good, if not excellent, technical emergency planning and preparedness guidance has been developed and published over the last few years by small groups of people at the national and international levels, but much remains to be done. For many reasons, overall emergency planning and preparedness for nuclear facilities has not yet reached a prudent and necessary level.

In summary, the justification and need for proper emergency planning and preparedness programs supportive of nuclear facilities stem from the fact that serious accidents have occurred, especially in recent times, and the fact that the expansion of the nuclear industry means many more facilities will become operational by the end of the century. An additional factor is that the first generation of nuclear facilities may become more prone to failures as they age and this could result in serious accidents. The last bastion of the 'defense-in-depth' concept has not received the support that it deserves. A high-visibility, adequate emergency planning and preparedness program, including satisfactory training programs, can help alleviate many of the fears surrounding the operation of nuclear facilities. Such a program would contribute to the overall safety of a high-technology industry; while it calls for an augmented commitment of dedicated, competent people, it involves a relatively small commitment in funds and resources to do the job properly.

ACCIDENT ASSESSMENT

Nuclear facility operators have the initial, unequivocal responsibility for accident assessment. This includes *prompt* notification of off-site authorities, accompanied by initial recommendations about any protective measures that off-site authorities should implement to protect the public health and safety. Prompt accident assessment and notification is particularly important for fast-breaking accidents. For slow-breaking events quick assessment and notification are also important, as a means for putting off-site authorities on a standby or alert status for mobilizing any required off-site response. Initial accident assessment should be followed by prompt specialized off-site radiological assessment by qualified governmental authorities. Until these authorities arrive on the scene, the nuclear facility operator should field radiological monitoring teams in the environs of the plant. The initial information gathered by these teams should be used to augment the information acquired by the nuclear facility operator from in-plant instrumentation. In the United States a new emphasis on in-plant identification of potential hazards represents a change from the previous emphasis in many operator response plans on measurement of actual levels of radioactivity before notification of off-site organizations and recommendation of actions to protect the public (USNRC 1979).

Time Factors Associated with Accidents Leading to Radiological Releases Off-Site

The planning time frames used by the NRC are based on design basis accident considerations and the results of calculations reported in the US Reactor Safety Study (USAEC 1975). The Reactor Safety Study's guidance cannot be very specific because of the wide range of time frames associated with the spectrum of accidents considered. Therefore, it is necessary for planners to consider the possible time periods between the initiating event and arrival of the plume, as well as possible time periods of releases in relationship to time needed to implement protective actions. The Reactor Safety Study indicates, for example, that major releases may begin in the range of a half hour to as much as 30 hours after an initiating event and that the duration of the releases may range from a half hour to several days, with the major portion of the release occurring within the first day. In addition, significant plume travel times are associated with the very adverse meteorological conditions corresponding to large potential exposures far from the site. For example, under the poor dispersion conditions associated with low windspeeds, two hours or more might be required for the plume to travel a distance of five miles. Higher windspeeds would result in shorter travel times, but would provide more dispersion, making high exposures at long distances much less likely. Therefore, if early notification of off-site authorities occurs for major releases of radioactive material, significant advance warning of high concentrations should be available in most cases. The warning time could vary somewhat for reactors whose containment characteristics differ from those analyzed in the Reactor Safety Study (USAEC 1975). The range of times given below, however, is judged suitably representative for the purpose of developing emergency plans.

A planning basis for the time dependence of a release can be expressed as a range of time periods in which to implement protective action. This range of values prior to the start of a major release is on the order of a half hour to several hours.

The subsequent time period over which radioactive material may be expected to be released is on the order of a half hour (short-term release) to a few days (continuous release). The US guidance (USNRC/EPA 1978) on the initiation and duration of releases may be summarized as follows:

- Time from the initiating event to start of atmospheric release: 0.5 hr to 1 day.
- Time period over which radioactive material may be continuously released: 0.5 hr to several days.
- Time at which major portion of release may occur: 0.5 hr to 1 day after start of release.
- Travel time of release to exposure point (time after release): 5 mi - 0.5 to 2 hr, 10 mi - 1 to 4 hr.

The time available for action is strongly related to the time consumed in the process of issuing a notification that conditions exist that could cause a major release or that a major release is occurring. Therefore the NRC is encouraging development and periodic testing of procedures for rapid notification.

Radiological Characteristics of Releases

To specify the characteristics of monitoring instrumentation, to develop decision aids for estimating projected doses, and to identify critical exposure modes, planners will need information on the radiological characteristics of potential releases.

Three dominant exposure modes have been identified for atmospheric releases from nuclear power facilities:

- whole body (bone marrow) exposure from external gamma radiation and from ingestion of radioactive material;
- thyroid exposure from inhalation or ingestion of radioiodines; and
- exposure of other organs (e.g., lung) from inhalation or ingestion of radioactive materials.

Any of these exposure modes could dominate (i.e., result in the largest exposures) depending upon the relative quantities of various isotopes released. Radioactive materials produced during the operation of nuclear reactors include fission products and transuranics generated by neutron exposure of the structural materials and other materials within and immediately around the reactor core. The fission products consist of a very large number of different kinds of isotopes (nuclides), almost all of which are initially radioactive. The amounts of these fission products and their potential for escape from their normal places of confinement have the greatest potential for consequences to the public.

Radioactive fission products exist in a variety of physical and chemical forms with varied volatility. Virtually all activation products and transuranics exist as nonvolatile solids. The characteristics of these materials show quite clearly that the potential for releases to the environment decreases dramatically in this order: gaseous materials, volatile solids, and non-volatile solids. For this reason, NRC guidance for source terms representing hypothetical fission product activity within a nuclear power plant containment structure emphasizes the development of plans covering the release of noble gases and/or volatiles such as iodine. However, particulate materials should not be completely neglected. Table 1 provides a list of dominant typical radionuclides for each exposure pathway.

Table 1. Radionuclides with significant contribution to dominant exposure modes.

Radionuclides with significant contribution to thyroid exposure		Radionuclides with significant contribution to whole body exposure		Radionuclides with significant contribution to lung exposure*	
Radionuclide	Half-life (days)	Radionuclide	Half-life (days)	Radionuclide	Half-life (days)
I-131	8.05	I-131	8.05	I-131	8.05
I-132	0.0958	Te-132	3.25	I-132	0.0958
I-133	0.875	Xe-133	5.28	I-133	0.875
I-134	0.0366	I-133	0.875	I-134	0.0366
I-135	0.280	Xe-135	0.384	I-135	0.280
Te-132	3.25	I-135	0.280	Cs-134	750
Kr-88	0.117	Cs-134	750	Kr-88	0.117
		Kr-88	0.117	Cs-137	11,000
		Cs-137	11,000	Ru-106	365
				Te-132	3.25
				Ce-144	284

*Derived from the more probable Reactor Safety Study core melt categories and from postulated design basis accident releases. Lung exposure is the dominant mode only when thyroid dose is reduced by iodine blocking or there is a long delay prior to releases.
SOURCE: USNRC/EPA (1978).

Emergency Communications

Because of the potential need to take immediate off-site action in the event of a significant nuclear accident, notifications to appropriate off-site response organizations must be made directly by the facility operator over reliable 24-hour/day communications systems with backup communications systems. The off-site response organizations that receive these notifications should have the capability to effectively communicate to members of the public immediate, predetermined actions based on recommendations from the facility operator. Since effective communications systems are the heart of any emergency plan, a great deal of attention must be paid in the emergency planning process to communications equipment, procedures, and periodic testing of the entire communications scheme. Radio communications to radiological monitoring teams in the field and the use of public radio and television to communicate with the public are key elements in emergency communications plans.

AN ADEQUATE PLANNING BASIS

What is an adequate planning basis for radiological emergencies at fixed nuclear facilities? This question (rephrased as, What kind of an accident at a nuclear facility should we plan for and prepare for handling?) was essentially asked by many US States and local governments and their national organizations some years ago. As a result of this inquiry, two US Federal agencies, the NRC and the EPA, launched an effort to determine an adequate planning basis for handling nuclear emergencies. In August of 1976, a joint US Nuclear Regulatory Commission/ US Environmental Protection Agency Task Force on Emergency Planning was formally appointed to look into this matter. In December of 1978, after 2 years of work, the joint NRC/EPA eleven-member Task Force unanimously concurred in and published its report, "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" (NRC/EPA 1978).

The "bottom line" on this Task Force report is that there is *no* specific nuclear power plant accident that can be identified as the accident that plans and preparedness programs should address. Rather, the Task Force stressed the need for planning for *consequences*, with only minimal concern for the *uncertainties as expressed by probabilities*. And, as a basis for improved planning, the Task Force recommended that essentially generic Emergency Planning Zones (EPZs) be established around all nuclear power facilities in this country. The Task Force further determined that the US Low Population Zone (LPZ) concept used for siting purposes had little real meaning in terms of off-site emergency planning and preparedness. The Task Force, in essence, rejected the concept of the "LPZ" for definitive and comprehensive emergency planning off-site. Further, the Task Force recognized the need to develop an emergency planning basis for addressing the so-called "Class 9" accidents, i.e., accidents resulting in extensive damage to, or melting of, the nuclear fuel core.

This need for a capability to accommodate emergency situations beyond the so-called "design basis accidents" used in plant and site evaluation makes generic rather than site-specific areas appropriate. The Task Force decided that the establishment of Emergency Planning Zones (EPZs) of about 10 miles for the airborne "plume" radiological exposure pathway and about 50 miles for the ingestion or food radiological exposure pathway would be sufficient to define the areas in which planning for the initiation of predetermined protective measures is warranted for any given nuclear power plant. The Emergency Planning Zone concept is illustrated in Figure 1.

Independent of the work of the US NRC/EPA Task Force, the Swiss Federal Office of Energy, Nuclear Safety Division, has

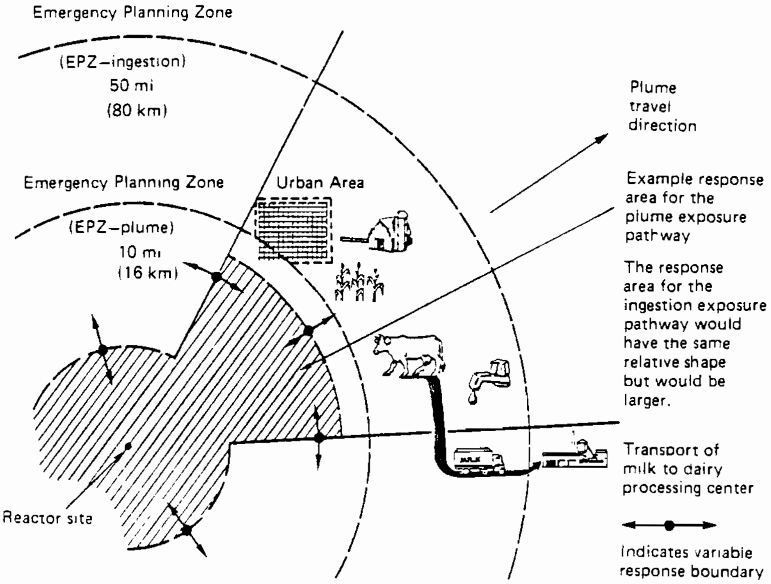

Figure 1. Emergency Planning Zones around nuclear power facilities in the USA, as established by the United States Nuclear Regulatory Commission/Environmental Protection Agency Task Force (USNRC/EPA 1978).

developed an Emergency Planning Zone concept very similar to the zones recommended by the NRC/EPA Task Force. The Swiss have 3 zones: an inner "Fast Alarm Zone" of about 2 to 6 kilometers, a second zone of 20 kilometers (12.5 miles), and a third zone (for the ingestion pathway) with no radius prescribed.

Although it was accompanied by some initial controversy and resistance from many quarters, the Task Force report is a major milestone along the way toward defining an adequate radiological emergency response planning basis. The report and the recommendations contained in the report were formally endorsed by the Commissioners of the NRC on October 5, 1979 and by the EPA Administrator on January 15, 1980. Steps are now being taken to put the Emergency Planning Zones concept into place around all power reactors in the US.

TRAINING

Emergency planning and preparedness programs have little value unless they are accompanied by well-conceived, comprehensive training programs. Training must be provided to personnel of all organizations who are perceived to have a role in both planning and operational response to emergencies, i.e., the preparedness function. Further, depending upon the functional roles of the various persons in the overall emergency response program, training needs are variable both in terms of subject matter and length of training programs.

A number of different types of training may be identified, corresponding to the various categories of organizations and personnel. Table 2 illustrates the possible involvement of various organizations in training programs. The NRC envisages two basic types of training: training in emergency planning and training in operational response. Exercises and drills are key components of the training programs.

Table 2. Training categories appropriate for various organizations and personnel involved in radiological emergencies. P is Training in Planning; G is General Operational Response Training; C/DM is Coordination/Decisionmaking Operational Training; ST is Special Technical Operational Training; E is Training in Exercises; and C is Coordination (only) Operational Training.

Organizations and Personnel	Training Categories
International organizations	P, C, ST, E
International (Regional)	P, C/DM, ST, E
National Governments	P, C/DM, ST, E
State/Provincial/Local Governments	P, C/DM, ST, E
Response-Oriented Subunits of Governments (Police, Fire, Civil Defense, Health, Environmental, Medical, etc.)	P (if not covered by planning functions of foregoing organizations), G, ST, E
Specialist Technical Teams	ST, E
Nuclear Facility	P, C/DM, ST, E

Training in planning is required for governmental organizations down to the level of individual, usually operationally-oriented, subunits. This type of training stresses learning how to put together effective organizational and interorganizational relationships. It also encompasses the development of emergency plans and the identification of what may be called 'essential planning elements'—the factors that should be considered in plans, such as accident assessment, protective measures, communications, notification schemes, and the identification of resources.

Training in operational response to a radiological emergency is required by all involved organizations and personnel. Training in operational response can be divided into three main types: *general, coordination/decisionmaking,* and *special technical.*

Generally, the staff of response-oriented subunits of government will be well trained to perform their primary functions, such as law enforcement, fire fighting, civil defense, and provision of health services. But these general response personnel need additional training to understand the nature of radiological accidents and the special considerations surrounding these accidents that may modify the way in which they perform their normal emergency duties or carry out additional duties. Radiological training for these general emergency response personnel need not be complex, but it should be comprehensive enough to enable them to work safely in or near a radiological environment. Some specialized training will have to be given to any response-oriented government subunits that will act in a special capacity, such as radiological monitoring teams.

At nearly every level of government there is a role for coordination and decisionmaking personnel during a radiological emergency. Training for these personnel should stress effective coordination of operational responses and analysis of incoming data, which is necessary for an effective decisionmaking process. In the operational response to radiological emergencies, there will also be a need for special technical teams of highly trained personnel.

Exercise scenarios should be developed to test emergency plans and operational response at all organizational levels. Standardized scenarios for different types of postulated accidents should be prepared. The scenarios should be designed to simulate meaningful on-site and off-site consequences requiring both on-site and off-site organizations to respond. Training programs focusing on the preparation of scenarios, conduct of exercises, and observation and evaluation of exercises are required at virtually every level of planning and response organizations.

An *exercise* is a training event that tests a major portion of the basic elements existing in an emergency plan; in effect, exercises test the operational response organization's overall ability to cope with a radiological emergency that could result in on-site and off-site consequences. Scenarios are required to effectively conduct an exercise.

As opposed to an exercise, a *drill* is a supervised instruction period aimed at developing and maintaining skills in a particular operation. A drill is often a component of an exercise, such as a communications drill, a radiological monitoring drill, or a fire-fighting drill. Drills to test small portions of the emergency plan should be conducted more frequently than exercises. Training in drills can generally be developed by supervisory personnel who handle such things as communications, radiological monitoring, and fire fighting on a day-to-day basis.

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EMERGENCY PLANS AND PROCEDURES AT UK NUCLEAR POWER STATIONS

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INTRODUCTION

All nuclear power stations operated by the Central Electricity Generating Board (CEGB) must prepare a detailed emergency plan before raising their reactors to power. Each emergency plan must be capable of dealing adequately with any feasible emergency situation. This includes situations that may give rise to the release of radioactive material or the emission of ionizing radiation, which could present a hazard to the public. The emergency plans are submitted to the Nuclear Installations Inspectorate (NII) of the Health and Safety Executive (H&SE) for approval. Before the reactors are raised to power a demonstration is held in the presence of NII representatives, and they must be satisfied of the adequacy of the station's Plan and Procedures.

This paper outlines in general terms the emergency plans that exist for operational stations of the Central Electricity Generating Board. The paper draws attention to the organizational aspects of the plans, rather than to the techniques employed for the measurement of radiation, for the control and repair of damage, and so forth. The paper ends with a brief comment on a review of these plans, which is currently being carried out within the CEGB.

EMERGENCY CONDITIONS

The CEGB operates eight sites on which there are twin gas-cooled magnox reactors. Twin advanced gas-cooled reactors (AGRs) are operational at one of these sites, and further AGRs are under construction elsewhere. At six of the magnox sites, the reactors have steel pressure vessels. At the two remaining sites, pre-stressed concrete pressure vessels are used. The consequences of a fault developing within the core differs for reactors with steel pressure vessels and those with prestressed concrete pressure vessels. Nevertheless, no distinction will be drawn between the two in this paper; the plans outlined refer more particularly to the steel pressure vessel stations.

Consideration of the accidents which could occur with such reactors led to the conclusion that plans should be prepared for dealing with the consequences of a fuel channel fire in a reactor with a fracture in one of its main coolant ducts (see Dale 1969). It is anticipated that such an accident, together with the resultant depressurization of the reactor, would give rise to doses in excess of 1 Emergency Reference Level (ERL) to people within 1 to 1.5 miles of the station. An ERL is defined as the radiation dose below which countermeasures are unlikely to be justified. The ERLs used in Britain are those recommended by the Medical Research Council (MRC 1969). As shown in Table 1, they include dose values in rem for the whole body and for a number of individual body organs.

Table 1. Emergency Reference Levels of dose recommended by the Medical Research Council.

Organ or Tissue	Dose (rem)
Whole body	10
Thyroid	30
Lung	30
Bone	
Endosteal tissue	30
Marrow	10
Gonads	10
Superficial tissue irradiated by β rays	60
Any other organ or tissue	30

A significant implication of such an accident is the need to have evacuation plans for people living within about 1.5 miles of the station.

EMERGENCY PLANS

Each station's plan is written to meet a legal requirement under the Site Licence and therefore relates to the particular station. Nevertheless all such plans follow guidelines laid down by the CEGB's Health & Safety Department (HSD), and consequently they are very similar in outline.

Two documents must be prepared at each site. The first is the Emergency Plan; it contains the principles of the scheme, the actions to be taken, and the responsibilities allocated to individuals. This Plan is the document that is approved formally by the

Health & Safety Executive. The second document is the Emergency Handbook; it gives details of the arrangements needed to put the Plan into operation. Both documents are regularly reviewed and updated and are distributed to representatives of all supporting organizations. A "Basic Emergency Plan," which is essentially applicable to any CEGB site, is published by the CEGB and deposited with libraries adjacent to all stations. A more complete description of the content of Emergency Plans is given in Emmerson (1969).

FUNCTIONS OF A SITE EMERGENCY ORGANIZATION

A site emergency organization has the following responsibilities:

- To assess the extent of any potentially hazardous situation on the site.
- To issue appropriate warnings at the correct time.
- To mobilize personnel and equipment to deal with a hazardous situation.
- To take measures to control the extent of a hazardous situation on the site.
- To carry out measurements of radiation and radioactive contamination both on the station site and in the areas surrounding the station.
- To assess the extent of any possible hazard to the public and to issue the appropriate warnings at the correct time.
- To provide advice and information for the control and movement of persons present in the vicinity of the station.
- To provide information for the control of milk supplies and other foodstuffs.
- To establish contact where necessary with the following bodies: CEGB Headquarters (National and Regional); Government Departments, in particular the Nuclear Installations Inspectorate; County Emergency Services, e.g., Police, Fire, and Ambulance; County and Local Authorities; Meteorological Office; River Boards and Water Undertakings; National Farmers' Union; United Kingdom Atomic Energy Authority.
- To provide information to the Public Relations Officer for issuing to the news media and to the public.
- To provide information on the resumption of normal conditions.
- To provide a record of events for later study.

STAFFING FOR EMERGENCY

A station is only staffed for normal operations. During normal (day) working hours, there will typically be some 300 people on site. At other times the total shift staff may only number up to 50 or so.

Senior Staff Positions. In the event of an emergency, the most senior officer would take charge of the emergency organization. The order of seniority is as follows: Station Manager; Deputy Station Manager; Operations Superintendent; Maintenance

Superintendent; Shift Charge Engineer on Duty. If emergency action was initiated by the Shift Charge Engineer, he would act as the Emergency Controller until relieved by a more senior officer.

The Emergency Controller is supported by staff trained as Emergency Health Physicists, Emergency Reactor Physicists, and Emergency Administrative Officers. Arrangements exist to ensure that staff trained to perform the duties of the above three officers are available "on call." They would be contacted immediately in the event of an incident and should be able to reach the site within a short period of time. Additional support staff could be summoned as necessary.

Other Staff. In the event of an emergency it is essential that all staff, together with any visitors or contractors on the site, assemble rapidly at designated muster points for a roll call. Subsequently the staff members would disperse to undertake the specific emergency duties for which they have been trained. The following teams would be formed:

(1) *Health Physics Teams.* Trained survey teams from the shift staff would be available to monitor radiological conditions both on and off the site. Their movements would be determined by the Emergency Health Physicist. Information on wind speed and direction, available on site, would indicate the path of any release of radioactivity.

Specially equipped health physics vehicles would be taken beyond the station security fence to determine the extent of any off-site contamination and to indicate whether or not any members of the public were at risk. A more complete explanation of these aspects has been given in Macdonald *et al.* (1977). On the plant site a similar assessment of radiological hazards would be carried out by teams equipped with portable instruments. The results of these surveys would be reported to the Emergency Health Physicist. He would then assess the radiological measurements and advise the Emergency Controller on the precautions required. Arrangements would also be made for the emergency issuance and processing of personal dosimeters (CEGB film badges).

(2) *Fire Teams.* A trained fire team from the shift staff would be available. The National Fire Service would be called to assist whenever necessary.

(3) *First Aid.* Two fully equipped first-aid centers must be maintained on site, one in or near the reactor block and the other in the Administrative Building. Persons trained in first aid would be nominated from each shift. Medical advice would also be available from the Station Nurse or the Regional Nursing and Medical Advisers.

(4) *Incident Assessment and Control.* A small team (the Incident Assessment Team) led by a trained engineer and including a Health Physics Monitor would make an initial rapid survey of the scene of an incident. During the initial survey, this team

would be in direct communication with the person in charge of on-site activities. On completion of the survey, the team leader would establish an Incident Control Point in the vicinity of the accident; he would then exercise local control of remedial action from this point.

(5) *Damage Control and Rescue Team.* A nominated supervisor would lead a damage control and rescue team, consisting of shift maintenance personnel and a health physics monitor. The supervisor would receive instructions from the Emergency Controller. The team would have been trained and equipped to rescue casualties, to contain and minimize the effects of the incident, and to stop the initial damage from extending. A major aim of the team would be to isolate the reactor from the atmosphere by temporarily sealing the fractured coolant circuit.

CONTROL CENTERS

All emergency actions on the site, together with any related off-site activities, would be directed from an Emergency Control Center located in the station administration block. In addition, there must be a second fully-equipped Emergency Control Center at an off-site location. This would be used if the situation on site made the use of the plant's own Control Center untenable.

If emergency action were initiated by the Shift Charge Engineer, the Station Control Room would be used as the Emergency Control Center until such time as the Shift Charge Engineer was relieved by the Duty Emergency Controller.

A Health Physics Control Point must be set up either in the Emergency Control Center or in a room adjacent to it. This facility is equipped with facilities for maintaining radio communication with the survey teams both on- and off-site. The results of all measurements of radiation dose rates, carbon dioxide concentrations, surface and airborne contamination levels, etc., would be reported to the Health Physics Control Point for interpretation. The Emergency Health Physicist would advise the Emergency Controller of any radiological precautions that may be necessary. The four senior staff involved in controlling and advising on the emergency situation, namely, the Emergency Controller, the Emergency Health Physicist, the Emergency Reactor Physicist, and the Emergency Administration Officer, would be located in the Emergency Control Center.

Support staff is provided for handling messages, carrying out plotting and calculations, etc., and this staff can be augmented as necessary. Each Center is equipped with large wall maps and charts in order to enable the radiological situation to be clearly presented to the Emergency Controller. In addition, each Center is stocked with radio communication equipment, public telephones, and a private automatic telephone exchange (PAX). There are also wind speed and direction recorders, monitoring instruments, appropriate stationery, and a library of emergency data, together with a full set of plant layout drawings.

COMMUNICATIONS

For on-site communication, each plant has a public address system that covers all operational areas, direct-wire telephones from the Station Control Room to key points within the station, a private automatic telephone system (PAX), and a staff-location system. Portable UHF radios are used extensively for short-distance communications and are particularly useful for the on-site teams.

For off-site communications, the station is served by a number of incoming Post Office telephone lines. There is also a direct telephone link with the Grid Control system. A further direct telephone link exists with the Public Relations Office, which is located within a few miles of the site; this link would be put into operation in an emergency. In addition, a VHF radio system covers a wide area around each site; it can be operated from the Emergency Control Centers and from the Health Physics Control Point.

COLLABORATION WITH OTHER AGENCIES

The organization, equipment, and technical skill available at each nuclear site is designed to cope immediately with the probable range of emergencies that may occur. Support arrangements exist for providing additional resources, assistance, guidance, and advice, should they be required. If the need arises, the responsibility for dealing with evacuation and related aspects would fall to the Public Services. This section of the paper summarizes the contributions made by supporting establishments and organizations under such circumstances.

CEGB Establishments.

(1) *Other Nuclear Power Stations.* In the event of any radioactive contamination outside the site, additional survey vehicles and trained crews would be dispatched from the nearest nuclear power station. These additional teams would assist local personnel in carrying out a survey of the area. If necessary, agricultural samples would be collected by the survey teams and taken to the District Survey Laboratory for assessment. All the CEGB's nuclear power stations have radiochemical and district survey laboratories available for evaluation of samples. There is a specialist facility at the Central Radiochemical Laboratory at Gravesend where radiochemical analyses can be carried out; similar comprehensive facilities also exist at the Berkeley Nuclear Laboratories of the CEGB. All of these can be manned to provide assistance as needed.

(2) *Nuclear Emergency Information Room (Region).* A Regional Emergency Information Room (REIR) would be set up in the region in which the affected nuclear station is situated. It would be manned by Regional Officers and support staff; their function would be to receive information from the Station regarding the cause of the emergency, the extent of injury to people, the extent of damage to the plant, the extent of spread of contamina-

tion, and any other relevant information. This information could then be disseminated to the senior management of the Region and to Headquarters.

Officers would go to the REIR as soon as possible after an incident has been reported. Personnel would be available to man the room on a continuous basis if this is required. It would be the responsibility of the staff in the room to answer requests from the Station for provision of resources, additional staff, specialist information, and so forth.

(3) *Nuclear Emergency Information Room (Headquarters).* A central Emergency Room (NEIR) is situated in the London Headquarters of the CEGB. The duties of the officers manning this room would be similar to those at the Regional Information Room, but on a national rather than a regional scale. The Headquarters staff would keep the Executive and senior management of the CEGB informed of the situation, would collaborate with Government Departments, the NII, and the Atomic Energy Authority, and would also have an important role to play in keeping Ministers advised. It is clear that highly specialized information would be available at the Headquarters that could be of value to the affected station.

NEIR would also keep the CEGB Headquarters Public Relation Office informed of the situation, i.e., information would be released to the media through the Headquarters Press Office as well as through a local information center.

(4) *Public Information Center.* A Public Information Center, equipped with a direct telephone line to the power station and a number of Post Office telephones, would be set up within a few miles of the affected station. Its function would be to issue statements on the situation in collaboration with the CEGB's Headquarters Press Office.

Outside Organizations

(1) *Police, Fire, Ambulance, and Welfare Services.* The County Police and the Local Authority must develop a comprehensive emergency plan for police, fire, ambulance, and welfare services. This plan forms part of their overall scheme for dealing with emergency situations in their area, such as flooding, fire, and major transport accidents. The Emergency Controller would inform the police of any emergency, and the police would then become the channel of communication with senior officials of the other emergency services and of the County Council. The Emergency Controller might also make direct requests for assistance from the local fire brigade or ambulance service. The police would set up a communications center near the Emergency Control Center and, if necessary, take steps to prevent access to affected areas near the site. Plans exist to issue potassium iodate tablets to the general public if a hazard arises from the emission of radioiodine (see Gregory 1972). The police would be responsible for issuing these tablets. If evacuation of particular areas becomes necessary, this would also be arranged by the police; they would proceed in accordance with their contingency plans, making use of

the Ambulance Service for moving people who are sick or infirm. The Emergency Controller would give advice on action in these situations.

(2) *Ministry of Agriculture, Fisheries & Food (MAFF).* The MAFF is responsible for controlling the distribution and consumption of milk and other foodstuffs which may be affected by an emergency, and also for controlling animal feed. The Ministry has prepared emergency plans to meet short- and long-term requirements. The function of MAFF would be, where possible, to ensure that no one was exposed to undue risks by consuming contaminated food, to make alternative foodstuffs available, and generally to mitigate any effects of the accident on agriculture, fisheries, and food.

The Regional Controller of the Ministry of Agriculture, Fisheries & Food, or one of his deputies, would receive direct warning of an emergency from the Emergency Controller. The Regional Controller would then send a representative to the site to direct actions that fall within the responsibility of the MAFF. In collaboration with the Emergency Controller, this representative would assess the results of surveys for radioactivity around the site. If it is necessary to collect samples for analysis from potentially contaminated areas, field officers of the MAFF would be made available to organize the collection.

(3) *United Kingdom Atomic Energy Authority.* It has been arranged that the Atomic Energy Authority would provide assistance if required within three hours of a request. The Authority would dispatch to the site vehicles with two-way radios operating on the same frequencies as those used by the CEGB radiation monitoring equipment, as well as trained Health Physics staff. The Authority would also prepare stocks of emergency equipment for transport to the site if they are needed.

(4) *Meteorological Office.* The Meteorological Office would provide frequent forecasts of weather conditions and wind direction in the area around the affected site. These data are essential for forecasting the path taken by any emitted plume of radioactivity, and also for carrying out assessments of probable exposures resulting from emissions from the site. Submission of a request for a weather forecast is a basic emergency procedure at all CEGB sites.

TRAINING OF STAFF

Adequate training of staff is essential for the correct functioning of emergency arrangements. The Nuclear Installations Inspectorate requires that such training be carried out systematically. This places a considerable work load on each of the nuclear stations.

The training programs are usually prepared by the station Health Physics Department, and the training periods are fitted into normal working hours. It has been found that training in small groups of six to ten persons is effective. Over the last few years increasing use has been made of training films and low-cost portable videotape recording units (see Emmerson 1969).

EXERCISES

Nuclear Site Licences require each station to "rehearse" its emergency arrangements. Currently each nuclear establishment carries out an annual demonstration emergency exercise, attended by observers from the Nuclear Installations Inspectorate and from the CEGB Health & Safety Department.

In addition to this demonstration, it has been found desirable to carry out exercises for each of the four or five shifts involved at each station, so that everyone is involved in a full scale exercise once a year.

Considerable ingenuity has been used to make the exercises as realistic as possible (Orchard and Walker 1977). Umpires provide instrument readings that may occur in real accidents (e.g., radiation dose rates, CO_2 in air, etc.). Casualties are usually "made up" to depict typical injuries, and active samples for counting purposes are substituted for the on-site and off-site air sample packs. Noise and smoke generators have been used to good effect in some exercises.

It is usual for some of the outside authorities involved in the emergency plans to take part in the exercises. The extent of participation varies, but the police forces take part in most exercises and the fire and ambulance services also turn out on many occasions. It is customary to perform "communications exercises" with local authorities, Ministries, and other parts of the CEGB's organization.

INFORMING THE PUBLIC ABOUT EMERGENCY PLANS

From the very outset of the Nuclear Power Programme, the CEGB has made determined efforts to keep the public informed of its intentions, and to explain the operations that are carried out at nuclear stations. To this end, a Local Liaison Committee (LLC) chaired by the Station Manager has been set up at each site. The members of this Committee represent local inhabitants and organizations, typically elected representatives and officers from local government and councils, representatives from local utilities such as the Water Boards, medical officers of health, and representatives from the police, the ambulance service, and the Farmer's Union, etc. The Committee meets with the Station management at least once a year. Representatives of the Nuclear Installations Inspectorate and the CEGB's Health & Safety Department attend this meeting, as do representatives of the Government Departments that authorize discharges of effluents from the site.

Local Liaison Committees receive clear explanations of the purpose of the Emergency Plan and the steps that would be taken to cope with any emergency situation. They are free to ask questions about implementation of emergency schemes. There is no doubt that the members of these Committees have helped to establish a sound organization for dealing with emergencies, by acting as ambassadors for the CEGB. They have explained the extensive emergency arrangements that have been prepared to their Council friends, neighbors, and constituents in the areas. The establishment of the LLCs has helped the local population to accept nuclear power stations; as well, the public has become accustomed to seeing exercises carried out.

CURRENT REVIEW OF EMERGENCY PROCEDURES

In common with virtually all utilities throughout the world since TMI, a review of our present plans and procedures is now being carried out. Because this review is still taking place, firm recommendations have yet to be made. The following areas have been singled out for closer consideration:

- The need to make provision for coping with an influx of large numbers (several hundreds) of newspaper, radio, and TV reporters to the area of the accident.
- The need to ensure that information supplied to the media is checked, to avoid conflicting reports and information.
- The possible need to assess collective doses in areas at considerable distances from the site of the accident.

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9

RADIOLOGICAL PROTECTION CRITERIA FOR CONTROLLING DOSES TO THE PUBLIC IN THE EVENT OF UNPLANNED RELEASES OF RADIOACTIVITY

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INTRODUCTION

The dosimetric criteria employed within the UK to limit the radiation exposure of members of the public resulting from unplanned discharges of radioactivity were originally recommended in a series of UK Medical Research Council reports (MRC 1959, 1960, 1961). These reports suggested the radiation doses that would warrant consideration of remedial action following the accidental escape of radioactive material to the environment; they also included data on the concentrations in air or in foodstuffs of several radionuclides, notably ^{90}Sr, ^{131}I, and ^{137}Cs, which would lead to these doses. In 1975 the Medical Research Council reviewed its original recommendations and presented revised and more comprehensive calculations, based upon metabolic and dosimetric data that had become available since the publication of the original reports (MRC 1975).

In August 1977 the Secretary of State for Social Services directed the National Radiological Protection Board to provide guidance to Government Departments and other appropriate bodies on the derivation of Emergency Reference Levels (ERLs). The Directive explained ERLs in the following terms:

> Emergency Reference Levels (ERLs) means the level of radiation dose below which countermeasures are unlikely to be justified. In the event of an accident involving, or likely to involve radiation doses to the public in excess of the dose limits set out in Direction 76/579/Euratom of 1 June 1976 laying down safety standards relating to Ionising Radiation, guidance to those with responsibilities for the protection of the public as a whole shall include guidance as to application of

> Emergency Reference Levels (ERLs) of dose. Within their function under Section 1 (1)b of the Radiological Protection Act 1970 the Board shall be responsible for specifying ERLs of dose. The Board shall also be responsible for providing guidance to Government Departments and other appropriate bodies on the derivation of ERLs relating to radiation exposure and radioactive materials in the public environment.

In an interim guidance report (NRPB 1978a), the Board suggested that the 1975 MRC recommendations should continue to apply while the Board consulted with regulatory bodies and other organizations who may utilize ERLs. This paper presents the current views of Board staff; they have resulted from consideration of the recommendations of the International Commission on Radiological Protection (ICRP 1977), as well as discussions with both operators of nuclear installations and those Government Departments who have a need for radiological protection guidance in the event of unplanned release of radioactivity.

The Board is now preparing a draft consultative document outlining its view on radiological protection in accident situations. Following discussions with all interested parties, the Board will finalize its advice to the operators and Government Departments concerned.

THE MEDICAL RESEARCH COUNCIL'S EMERGENCY REFERENCE LEVELS

The ERLs of dose for members of the general public proposed by the Medical Research Council in 1975 were set equal to the doses that could be received over two years by workers occupationally exposed to the "Maximum Permissible Annual Doses" then in effect for individual organs and tissues—as specified by the International Commission on Radiological Protection (ICRP 1966). The ERL of dose to the thyroid, however, was set at the dose that could be received by a worker in a year. This value was chosen because the thyroid tissue of juveniles may be more radiosensitive than that of adults (ICRP 1966).

These currently recommended ERLs of dose are given in Table 1. The separate identification of endosteal tissue and bone marrow (rather than the mineral bone itself) represents a departure from the 1966 ICRP recommendations; these two tissues have been identified as the relevant tissues at risk following irradiation. The ERLs of dose applied to the whole body or to each organ or tissue irradiated separately. In the event of simultaneous irradiation of several organs, the tissue receiving the greater dose relative to its ERL became the critical tissue for comparison with the ERL and determination of countermeasures. The MRC (1975) defined the ERL as the radiation dose below which countermeasures are unlikely to be justified; it stated that when a radiation dose seems likely to exceed the ERL, countermeasures should be undertaken—provided that a substantial reduction in dose is likely to be achieved and provided the countermeasures can be undertaken without undue risk to the community.

Table 1. Emergency Reference Levels of dose recommended by the Medical Research Council (1975).

Organ or Tissue	Dose (rem)
Whole body	10
Thyroid	30
Lung	30
Bone	
Endosteal tissue	30
Marrow	10
Gonads	10
Superficial tissue irradiated by β rays	60
Any other organ or tissue	30

The ERLs were not put forward as firm action levels, but rather as dose levels which responsible authorities should use to judge whether countermeasures should be introduced, taking full account of the disadvantages and risks that these countermeasures might create. When a release of radioactivity is uncontrolled, as after an accident, public exposure can only be limited by countermeasures that interfere with normal living conditions, such as evacuation, the closing of areas, sheltering, the control of food supplies, and in the special case of the release of short-lived isotopes of iodine, the administration of tablets containing stable iodine to the exposed population.

PRINCIPLES INVOLVED IN DEVELOPING REVISED RADIOLOGICAL PROTECTION CRITERIA FOR ACCIDENTAL RELEASES

The National Radiological Protection Board is now reviewing ERLs and the criteria that should be developed for the protection of the population from unplanned releases of radioactivity; this review is being performed in the light of the publication of the latest recommendations of the ICRP (1977) and present knowledge of the risks of deleterious effects following irradiation.

ICRP recommendations (1966, 1977) have consistently stated that in the event of an accident the hazard or social cost involved in any remedial measure must be justified by the resulting reduction of risk. Because of the great variability of the circumstances in which remedial measures might be considered, the ICRP has not recommended "intervention levels" appropriate for all occasions. However, the ICRP feels that for foreseeable types of accidents it may be possible to gauge—by an analysis of the accident and remedial action—levels below which it would *not* be appropriate to take action.

The latest ICRP recommendations (1977) emphasize that the decision to initiate remedial action will have to be based on the particular circumstances prevailing at the site at the time of the incident. These include geographical, meteorological, and social conditions. In general, the principle involved in deciding whether to institute countermeasures is that the social cost and risk of the countermeasures should be less than those that would otherwise result from exposure. Consequently, those responsible for health and safety at any nuclear installation will have to prepare an emergency plan that includes the dose levels at which the various countermeasures would have to be considered. ICRP has left the setting of such levels for particular circumstances to national authorities.

In developing radiological protection principles, it is important to distinguish between criteria established for the introduction of countermeasures and the possibly different criteria for returning to a normal situation following the accident; in the latter case long-term consequences may have to be taken into account. The emergency criteria discussed below relate to the introduction of short-term countermeasures, not to the longer-term avoidance of dose—for example, by the banning of foodstuffs. Decisions on the imposition of a food ban or replacement animal feeds can usually be left until a later stage in the development of the accident sequence, when the extent of public exposure can be better estimated. The time scale envisaged for this process is a day or two.

The costs and risks to the population associated with the banning of foodstuffs such as milk are minimal, except in the event of a catastrophic accident when there might potentially be an overall shortage of food supplies. Consequently, the decision to ban foodstuffs would probably be made at a rather low level of dose to the individual, lower than that for the introduction of other countermeasures.

SPECIFICATION OF THE RISKS ASSOCIATED WITH EXPOSURE TO IONIZING RADIATION

Effective Dose Equivalent and Annual Dose Limits for Members of the Public

Publication 26 of the ICRP (1977) specifies risk coefficients for certain health limits for occupationally exposed workers. The risk coefficients apply to the incidence of fatal cancer in a range of human body organs and tissues, together with the risk of hereditary effects in the two subsequent generations. These risk coefficients are shown in Table 2, together with the relative weighting factors w_T to which they correspond; the ICRP used these factors to define the Effective Dose Equivalent H_E:

$$H_E = \Sigma \, w_T H_T$$

where H_T is the dose equivalent in tissue T.

The principle involved in establishing the Effective Dose Equivalent is that the level of risk to the individual should be the same, whether the body is irradiated uniformly or whether selective organ or partial body irradiation occurs.

Table 2. Risk coefficients and weighting factors set forth in ICRP Publication 26 (1977).

Tissue	Risk $(10^{-4}\mathrm{Sv}^{-1})$ $(10^{-6}\mathrm{rem}^{-1})$	w_T
Gonads	40	0.25
Breast	25	0.15
Red bone marrow	20	0.12
Lung	20	0.12
Thyroid	5	0.03
Bone	5	0.03
Other tissues	50	0.30
TOTAL	165	1.00

The quantity Dose Equivalent is considered suitable for describing the incidence of stochastic effects of doses received following accidental releases of radioactivity; for stochastic effects the probability of an event occurring rather than its severity is regarded as a function of dose without threshold. The stochastic dose limit for members of the public, as recommended by ICRP and endorsed by the Board (NRPB 1978a), corresponds to an Effective Dose Equivalent of 5 mSv (500 mrem) in a year.

Nonstochastic effects are those for which the severity of the effect varies with dose and for which, therefore, a threshold may occur. For continuously exposed workers and members of the public, the ICRP (1977) introduced nonstochastic annual dose limits to prevent the incidence of such effects, which are specific to particular tissues; these effects include cataract of the lens of the eye, nonmalignant damage to the skin, cell depletion in the bone marrow causing hematological deficiencies, and gonadal cell damage leading to the impairment of fertility. For members of the public, the ICRP recommends a nonstochastic annual dose limit of 50 mSv (5 rem) to any organ or tissue, with the exception of the lens of the eye; this tissue has a limit of 30 mSv (3 rem). The annual dose limits for nonstochastic effects are clearly intended to limit lifetime exposure to particular tissues and will *not* be applicable in an accident situation.

It is necessary to consider whether the Effective Dose Equivalent is a sufficient quantity to express risks to individual members of the public in the event of unplanned releases of radioactive materials. According to the data in Table 1, the risk of fatal cancer is $1.25 \times 10^{-2}\mathrm{Sv}^{-1}$ $(125 \times 10^{-6}\mathrm{rem}^{-1})$ for uniform whole body irradiation; for individual single organ irradiation, such as the thyroid, the same risk of fatal cancer is achieved by giving a dose to that organ 25 times higher than the whole-body dose. This is a particularly important point because of the likelihood of selective thyroid irradiation following a reactor accident. Such an accident may release isotopes of iodine that concentrate in the thyroid. For routine exposure this problem does not arise as severely; the nonstochastic dose limit will ensure that the dose to any one organ is no more than 10 times higher than the stochastic dose limit.

Radiation Risks not Included in the Definition of Effective Dose Equivalent

Hereditary Effects in all Future Generations

The quantity Effective Dose does include a component of genetic risk, i.e., the incidence of serious hereditary ill health in the first two generations following irradiation. The total incidence in later generations is of the same magnitude; thus inclusion of the hereditary effects in the first two generations accounts for half the total number of effects. For the purposes of decision making in accident situations, it is considered sufficient to include the genetic effects in the first two generations. Thus Effective Dose is satisfactory from the point of view of estimating risks to individuals. But for the purposes of calculating total detrimental health effects in the population following an accidental release of radioactivity, the hereditary effects in all future generations should be included.

Nonfatal Cancer Incidence

The risks of irradiation discussed so far do not include the incidence of nonfatal cancers. These are defined as cancers for which survival is high, although there may be appreciable loss of quality of life for physiological or psychological reasons. It is now thought that the incidence of nonfatal cancers could be two or three times the incidence of fatal cancers following uniform whole-body irradiation. These cancers would arise mainly in the breast, skin, and thyroid (ICRP 1978). Clarke and Smith (1980) have suggested the nonfatal incidence of cancers averaged over age and sex shown in Table 3. The values are in line with estimates given by the United Nations Scientific Committee on the Effects of Atomic Radiation for thyroid, breast, and skin cancer incidence and fatality (UNSCEAR 1977).

Of particular interest here is the high incidence of thyroid cancer. (This does not include the numbers of benign nodules that may occur.) Nonfatal thyroid cancers may be accompanied by severe physiological and psychological problems. Nonfatal skin cancers may be more easily treated and cause less long-term distress. Because of the possibility of the release of isotopes of iodine from reactor accidents and its selective concentration in the thyroid, it is felt to be necessary to limit thyroid irradia-

Table 3. Incidence of cancer following irradiation and percentage fatality.

Organ	Incidence		Percentage fatality	Nonfatal incidence	
	Sv^{-1}	(rem^{-1})		Sv^{-1}	(rem^{-1})
Breast	5.0×10^{-3}	(50×10^{-6})	50	2.5×10^{-3}	(25×10^{-6})
Skin	10^{-2}	(100×10^{-6})	1	9.9×10^{-3}	(99×10^{-6})
Thyroid	10^{-2}	(100×10^{-6})	5	9.5×10^{-3}	(95×10^{-6})

SOURCE: Clarke and Smith (1980).

tion under these circumstances on the basis of the incidence of thyroid cancer, rather than just on the basis of fatal cancer risks to the thyroid.

Thus, if the risk of fatal cancer following uniform whole body radiation is taken as about $10^{-2}Sv^{-1}$ $(10^{-4}rem^{-1})$, averaged over age and sex (ICRP 1978), the risk to the thyroid of malignancy—if that organ is irradiated in isolation—is considered to be the same.

APPLICATION OF THE RISK CRITERIA

Principles

The ICRP (1977) has indicated that its dose equivalent limits are intended to apply only to conditions where the source of exposure is under control. The Commission emphasizes that its recommended limits are set at a level thought to be associated with a low degree of risk; thus, unless a limit were to be exceeded by a considerable amount, the risk would still be sufficiently low as not to warrant countermeasures involving significant risks or undue cost. Therefore, it is clear that it is not obligatory to take remedial action if a dose equivalent limit has been exceeded.

However, there may well be the possibility of deciding upon a level of dose *below* which it would be unnecessary to consider the possible introduction of countermeasures. There will be, similarly, some upper level of exposure at which countermeasures will definitely be instituted, e.g., attempts to avoid early effects of acute irradiation.

Thus, the philosophy for dealing with radiation protection in accidents is to propose a two-tier dose system, as shown schematically in Figure 1. Beyond the lower dose bound one must continually consider the possibility of introducing countermeasures in the short term (evacuation, distribution of stable iodine tablets to prevent radioiodine uptake in the thyroid), while com-

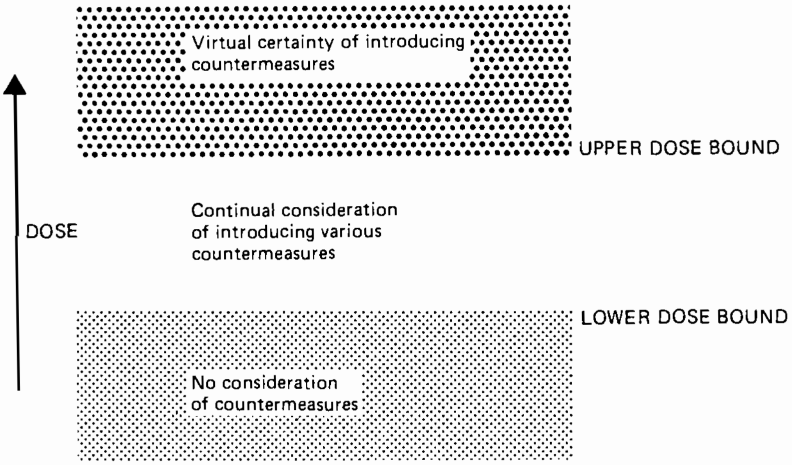

Figure 1. Proposed principles for establishing radiological protection criteria for accidents: a two-tier dose system.

paring the risks from the irradiation with the risks of the countermeasures. The risks associated with the countermeasures are extremely difficult to quantify. They will probably depend upon the size of the population, its distribution, and certainly on the local geography and the conditions pertaining at the time after the start of the incident; for example, the risks of evacuation in extremely adverse weather conditions will be very different from those that might otherwise apply.

The staff of the National Radiological Protection Board therefore consider that it should be left to individual sites, in their preparations for emergency planning, to consider the range of consequences of various countermeasures that might be invoked. Each site should agree upon Action Levels with regulators, depending on the nature of the accident and conditions existing at the time.

Establishment of the Lower and Upper Dose Bounds for Decision Making in Accident Situations

For planned releases involving exposure of members of the general public to radioactive wastes, the Board has advised that the dose equivalent limit to the whole body should be 5 mSv (0.5 rem) in a year (NRPB 1978b). This figure is based on risk considerations and the possible lifetime exposure of the individual. Publication 26 of the ICRP implies, on the basis of risk considerations, that the annual dose equivalent limit for individual members of the public is 1 mSv (0.1 rem), if the dose is actually received as a lifetime exposure of the whole body.

It thus would seem reasonable that if the estimated exposure of individuals was not likely to exceed an Effective Dose Equivalent of 5 mSv (0.5 rem) in an unplanned release, there would be little need to consider short-term countermeasures. This effective dose corresponds to a level of fatal risk of about 5×10^{-5}; it would require a cohort of 20,000 people exposed at this level to give rise to a prediction—on the linear hypothesis relating dose to risk—of one statistical death in a time period of perhaps 40 or 50 years following the irradiation.

On the basis of the incidence of thyroid malignancy, the same dose level of 5 mSv (0.5 rem) can be taken as the lower-bound dose of thyroid irradiation, below which short-term remedial actions would be unwarranted. In the interests of developing simple principles, the same lower dose bound is proposed for irradiation of the skin. This level of dose to the skin corresponds to the same risk of cancer incidence as for the irradiation of the thyroid, although the consequences are much less severe.

The principle followed in setting the upper dose bound is that attempts should certainly be made to avoid the risk of early adverse effects of acute irradiation. Although the LD_{50} (dose corresponding to 50% chance of lethality) for whole body irradiation is about 350 rad without medical supportive treatment, a considerably lower dose would be appropriate for a general population including the young, the old, and the chronically sick. In fact, it is felt that all attempts should be made to avoid the early nonfatal effects of acute radiation; as a consequence, the Board is suggesting an upper dose bound of 0.5 Sv (50 rem) effective dose equivalent. If it is likely that population groups would exceed this level of dose, then countermeasures should be considered mandatory.

In the case of selective irradiation of the thyroid and the skin, upper bound dose equivalents of 0.5 Sv (50 rem) have again been chosen—partly on the grounds of providing simplicity and partly on risk grounds. The dose of 0.5 Sv to the thyroid corresponds to a risk of malignancy of 0.5×10^{-2} to the individual. This is considered to be a high level of risk, and the risks of administration of stable potassium iodate or of evacuation are virtually certain to be less than this figure.

In summary, the proposed dose range for action following accidental releases of radionuclides are shown in Table 4. The doses are effective dose equivalents, or dose equivalents to thyroid or skin. These proposed criteria apply only to the introduction of countermeasures; different principles will be followed for the return of the population, once evacuated, to contaminated buildings or lands.

Table 4. Proposed dose range for action following accidental releases of radionuclides.

Dose range	Action
0-5 mSv (0-0.5 rem)	No action
5-500 mSv (0.5-50 rem)	Continual consideration of introducing countermeasures
>500 mSv (>50 rem)	Certain action

Contamination of Foodstuffs

In many accident scenarios, ground contamination will follow the accidental release, and contamination of foodstuffs, particularly milk, can be foreseen as a consequence of the release. In the case of contamination of foodstuffs, there is probably more time to make a decision regarding the banning of consumption—typically a day or two. In this case there is time to assemble an expert team to advise and consider the exposure of the public and the effects of countermeasures. There is very little penalty in not distributing fresh milk, and it may be that decisions could be made to instigate milk bans to restrict the dose to members of the public to well below the suggested lower bound dose equivalent of 5 mSv (0.5 rem).

SUMMARY

The principle to be followed in planning the protection of the population from unplanned releases of radioactive material is that the risks of the countermeasures should be less than the risks of the radiation that would otherwise be received.

The risks of countermeasures are variable depending upon the size of the population, its composition and distribution, the location, and the conditions pertaining at the time of release. For these reasons it is not considered possible to recommend any single level of dose as a reference for preplanning radiological protection for accident situations.

On the basis of risk considerations, the National Radiological Protection Board staff propose a two-tier system of reference doses for use in preplanning for an accidental release of radioactivity to the environment, as well as for short-term decision making in the event of such a release. The lower dose bound is set such that no action is necessary if doses are unlikely to exceed this dose. If doses are likely to exceed the lower dose bound, then the introduction of countermeasures should continually be evaluated on the basis of net risk avoidance.

The development of Action Levels for the introduction of countermeasures above this lower dose bound is considered to be the joint responsibility of operator and regulator. The Action

Levels should be based on a complete analysis of potential accident sequences and consequences for the particular plant and its actual location. Action Levels are, therefore, expected to be site-specific. The Action Levels must also demonstrate flexibility, so that conditions prevailing at the time of an accident may influence the decisions on the introduction of countermeasures.

The upper dose bound has been set at a level of dose at which countermeasures are certainly expected to be implemented. The principle proposed here is the avoidance of any early effects of acute irradiation in the general population.

The above recommendations apply to short-term decision making in the event of an accident. In the case of contamination of foodstuffs, there is a longer time scale to evaluate the consequences to the public; the social cost and health risk to the public from the banning of fresh foodstuffs or the introduction of supplementary feeding of grazing animals will generally be very small. Therefore, there is incentive to introduce controls on foodstuffs at doses that may be significantly below the lower dose bound proposed here.

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10

RISK MANAGEMENT AT THE NECKARWESTHEIM PLANT IN THE FRG

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The GKN-Neckarwestheim nuclear power plant, which is located between Stuttgart and Heilbronn, began operation in 1976. The KWU (Kraftwerk Union Aktiengesellschaft) 3-loop pressurized water reactor has a net output of 800 MWe. The plant's special accident management features include

- Four redundant emergency installations in four secure and separate buildings. These are equipped with diesel generators and all electronics and switching systems necessary to maintain a safe standby shutdown of the plant for up to 10 hours without human intervention.
- An automatic shutdown system for cases of small- and medium-sized leakages. This system ensures that the reactor is cooled down before leakage water is pumped back.
- Small safety valves for every secondary loop. These are able to release the shutdown power in hot standby without electric drive. These safety valves can be isolated if a defect occurs.
- A loose-particle monitoring system for the primary circuit.
- A system of TV cameras at several points within the containment.
- An acoustic system to transmit the containment noise into the control room.
- A special computer that indicates criteria to be met before an intended operation can be performed and an "accident catching" tape-recording system that holds selected signals for the interpretation of fast transients. These supplement the usual recorders and process computer.

Most of these systems were installed after our plant began operation. They result from lessons learned from failures at other plants or from theoretical discussions. The installation of these systems results from our belief that risk management should not be ignored until an accident occurs and that preparedness implies much more than just administrative action. The necessity for continuous appraisal and subsequent installation of special devices to improve a plant is not widely appreciated. I am glad that the owners of the plant discussed in this paper are willing to bear the costs for such installations. Although we do not allow ourselves to believe that the plant will never have an accident, we feel that the operating team has an excellent opportunity to detect failures in good time and to find ways of combating them.

Several measures can be taken to improve plant safety, including

- Quality control during the construction phase;
- Repeated inspections of the materials and functioning of systems and components during the lifetime of the plant;
- Automatic systems for accident management;
- Well-trained operators.

However, all such measures taken together are not capable of totally precluding failures.

In case of a sudden event, everything that must be accomplished in seconds must be carried out by automatic systems. To date, I do not know of any failure that could not be contained within several minutes by the available automatic systems, even in the case of a tube rupture. Because of the presence of redundant and diverse systems, many parallel failures in the plant can be managed without serious consequences.

A good control room team needs only a few minutes to determine that something is wrong and that action is necessary. If all indicators show characteristics of a type of accident that had been previously analyzed, the team should be able to identify required actions in a short time. Actually, in such cases the operators could be replaced by a computer. However, I think it is impossible to predict all combinations of failures in such a way that correct emergency procedures can always be prepared in advance. Space flight experience has shown that even the best automatic system is not perfect and that human thinking is still vital in unpredictable situations.

If there is an unexpected, uncalculated series of failures in a plant, one's philosophy may be based on one of two modes of desired action: (1) The operators may be allowed to act only as they have been instructed and trained. If there is a sequence of unforeseen failures, they must call for assistance and wait, whatever happens. (2) The operators may be told to behave as instructed for as long as possible, but to pay careful attention to special complications and to react—if necessary—appropriately. Engineer-operators are not required for the second mode, because knowledge of which actions to take results largely from a high degree of familiarity with the plant and plant operations. This familiarity is typically found in people with more than 10 years of local experience and is not typically found in engineers.

We consider the second mode to be the correct procedure, because in practice one can only expect optimal, not perfect, preparation. Minor inadvisable, yet harmless, action is better than no action whatsoever, with an unforeseeable risk. To date, no event has occurred that has not been foreseen. Hopefully inadvisable decisions will never be made, becàuse the situation that could lead to such a decision will never occur. However, as such situations cannot be excluded totally, shift foremen should always be available for decision making.

If any incident occurs at the plant that the operators consider abnormal, they must call for engineers and specialists on standby. This staff should be at the plant within about half an hour and form the basis of the *plant staff's* risk management team. Within two hours at the most, a staff of engineers (including experts in operations, processes, mechanics, electric systems, electronics, and computers), a physicist, a chemist, and a radiologist should assemble to analyze the incident and determine the actions required. This group needs working space close to the control room. While the operators keep the plant in a stable state, this specialist staff should study computer printouts and other records, compare the facts thus obtained with the plant's technical documents, evaluate possible consequences, and, if necessary, inform the government authorities' crisis staff and call specialists for assistance.

The plant staff is headed by the plant superintendant or a deputy. He gives orders about the operation of the plant to the shift foreman through the operation branch manager. It is helpful if there is someone to write minutes and another person to handle necessary telephone or telex messages and to look for additional information. Only limited and well-prepared statements and information should be disseminated outside the plant. Only the head of staff should give or order such statements. If required, an expert from the government authorities can be recruited to give advice to the staff and forward questions to any external group of experts; but he should not give orders to the plant staff or make statements or give information that have not been cleared by the head of staff.

For maximum effectiveness, the staff should consist of not more than about fifteen people (with not more than one person from outside the plant). In order to avoid diversions, telephone messages to the staff should only be made through the telephone operator. Only certain connections should be allowed. In addition, the plant staff may have a direct emergency telephone. Permission to enter the plant should not be given to anyone who does not have to be there. This is a necessary rule, not only in case of crisis, but also in less serious cases—to prevent the situation from developing into a crisis!

For efficiency, the plant staff should be isolated. Therefore another team must be available close to the plant to obtain information from the on-site staff and provide all public institutions including the press, the owners of the plant, and the local authorities, with up-to-date reports. This *information staff* also should act as relief to the plant staff, for instance to arrange transportation for personnel and supplies and to accept all telephone calls from the outside except those from other personnel to the plant staff. This information staff should be headed by a responsible member of the plant administration and he should be assisted by other plant experts. This group's most important task is to coordinate information about the plant in order to avoid public confusion, such as that experienced during the TMI accident.

The *crisis staff* of the appropriate authorities should get direct information only from the plant staff. This crisis staff should be the sole connection between the plant staff and all authorities and public institutions such as the police during a crisis. Another paper in this volume (see Chapter 12) deals with how the crisis staff makes decisions.

The radiological investigations and laboratory activities necessary in the vicinity of the endangered plant should be performed by the staff of neighboring plants, supervised by one of the affected plant's own radiologists. Four nuclear plants have contracts to give mutual assistance to the Neckarwestheim plant. The plant personnel must be vigilant 24 hours a day. In case of an evacuation, a rendezvous point is designated 5 miles away; from this point the police can transport supplies to the plant.

Another contract for planned assistance from specialists on the staff of the construction company is in preparation. By means of an on-line telephone and telecopy system, it should be possible—within a few hours of an accident—to exchange information, records, questions, and advice between the plant staff and the staff of the construction company. Thus, the plant staff should have every possibility of giving the best instructions to the shift foreman and the best information to the crisis staff. Figure 1 summarizes the groups of actors involved in the management of a crisis at a nuclear plant.

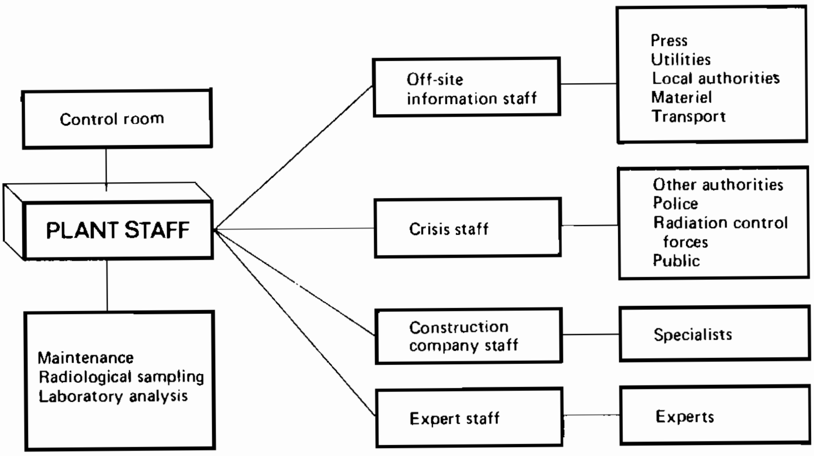

Figure 1. Organization of risk management staff to be mobilized in the case of a crisis at the Neckarwestheim nuclear power plant.

A practice exercise in 1978 showed that it is very important for personnel to have experience in communications. In particular, a reliable personal understanding of procedures must be gained without the stress of an accident situation.

It is unacceptable for representatives of government authorities—as good as their technical knowledge may be—to give instructions to the plant staff. It is not considered restrictive, for example, if the plant superintendent and a government official decide jointly at what time radioactive gases are to be released, but all decisions about the plant itself must be made only by the plant superintendent, assisted by his own staff. These decisions must be the result of the best estimate of the plant staff. Estimates of an extremely conservative worst-case nature should be considered in theoretical discussions but should not be incorporated into risk management. The situation must never arise where, during a case of a serious failure, the plant staff's decision making is affected by panic outside the plant. Neither political nor financial pressures should be tolerated while danger to the environment remains.

The people within the plant bear quite a lot of personal risk. Trust and assistance are the best means of helping the people who must operate the plant—even when the plant has suffered failures.

It is hoped that accidents that constitute a crisis will never occur. In any case, with the measures undertaken, such incidents should be very rare. Thus, ironically, it is very difficult for personnel to gain knowledge about the potential and real risks that are experienced during operation of nuclear plants, and the accident-management staff has very little chance of experiencing other realistic exercises such as military maneuvers. But one has, of course, to be thankful that, in preparing this paper on the Neckarwestheim plant, one difficulty was the absence of data from an actual crisis incident. I hope that this situation will remain unchanged and that the preparations already made for crisis management in all nuclear facilities will be sufficient, but never tested by actual experience.

11

EMERGENCY PLANNING IN THE VICINITY OF NUCLEAR INSTALLATIONS

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INTRODUCTION

Nuclear installations have to be planned, designed, constructed, and operated in such a way that no incident could threaten the health of the public. Strict supervision on the basis of stringent technical and radiological regulations must ensure the safe operation of nuclear facilities.

In spite of great research and development efforts in the field of reactor safety, a certain statistical risk remains and has to be borne and managed. For this reason, the general system of disaster control in the Federal Republic of Germany (FRG) has been reinforced by additional specific countermeasures to be implemented in the vicinity of nuclear power plants.

ASPECTS OF THE FEDERAL SYSTEM OF EMERGENCY MANAGEMENT

The states within the FRG are responsible for planning, equipment, and training in the field of emergency response. The Federal Government provides equipment and personnel from its Civil Defense resources and offers advice in specific nuclear matters. The measures taken by the various states of the FRG are coordinated and enable emergency planning and action across state borders with minimal delay.

The authorities of the various states have prepared detailed emergency plans for each nuclear power plant, in accordance with a document worked out by the states, the "Basic Recommendations for Disaster Control in the Environment of Nuclear Installations" (Bundesministerium des Innern 1975). Delegation of responsibility to local authorities has proved to be a sensible step. Knowledge of local circumstances and personal acquaintance with the appropriate officials save time in communication and implementation of necessary countermeasures. Many of the people involved are volunteers.

RADIATION DOSES REQUIRING COUNTERMEASURES

The maximum permissible dose for a radiation worker is 5 rem per year. This value is also the maximum design guide dose for an individual per incident (Strahlenschutzverordnung 1976). Three major measures that can be taken in an accident situation are

- staying inside the house, i.e., taking shelter (almost every house in the FRG has a cellar),
- taking iodine tablets for protection of the thyroid gland,
- evacuation.

Tables 1 and 2 provide a list of countermeasures for various dose levels. From these tables it is clear that the aim of all measures is to keep radioactivity and human beings apart, by sheltering or by physiological blocking of the intake of radioactive material, or ultimately by removal from the place of possible hazard.

Table 1. Recommended countermeasures for whole-body irradiation by external exposure and inhalation, by dose level.

	Recommended emergency measure	
Whole-body dose (rem)	Shelter	Evacuation
200	Mandatory until evacuation	Mandatory
100		
50	Mandatory	Recommended
25		
10	Recommended	None

SOURCE: Hardt *et al.* (1977).

ORGANIZATION OF EMERGENCY MANAGEMENT ACTIVITIES

Figure 1 shows how interaction among Federal and State authorities, the operator of a nuclear power plant, and the local authorities is organized. According to this scheme, the responsibility for emergency planning and management lies with the local government of a district. The Federal and State governments each send experts to the emergency operation control staff to give specific nuclear advice, as does the licensee of the plant in question.

Table 2. Recommended countermeasures for irradiation of the thyroid gland by inhalation of radioiodine and radiotellurium, by dose level.

Dose to the thyroid gland (rem)	Recommended emergency measure		
	Shelter	Iodine tablets	Evacuation
1000	Mandatory until evacuation	Mandatory	Mandatory
500			Recommended
200	Mandatory	Mandatory	Not necessary
100			
50		Recommended	
25			
10	Recommended	Not necessary	None

SOURCE: Hardt *et al.* (1977).

The organizations participating in emergency management are equipped with instruments for specific purposes, e.g., to measure the degree of possible contamination of a victim. Organizations such as the Red Cross plan and organize the training of their members (many of which are volunteers) under the supervision and on the basis of recommendations of the state and Federal authorities. Exercises organized at irregular intervals ensure an adequate level of training for emergency personnel. The public does not participate in the exercises, since possible disturbances may cause more harm than the positive effects of the exercise.

EXPERIENCE GAINED FROM EXERCISES AND THE THREE MILE ISLAND ACCIDENT

After an incident has been reported to the authorities by the operator of a nuclear installation, an immediate assessment has to be made of the possible extent of the problem. This initial evaluation provides the basis for all countermeasures to be taken. The accident at the Three Mile Island plant took such an unfortunate development because of the lack of correct information on the status of the plant.

The government of the FRG will improve the standard of education and training of plant personnel and will provide recommendations for better drill and ergonomic equipment. For the teams carrying out measurements in the respective area, better instruments and a more thorough education are necessary.

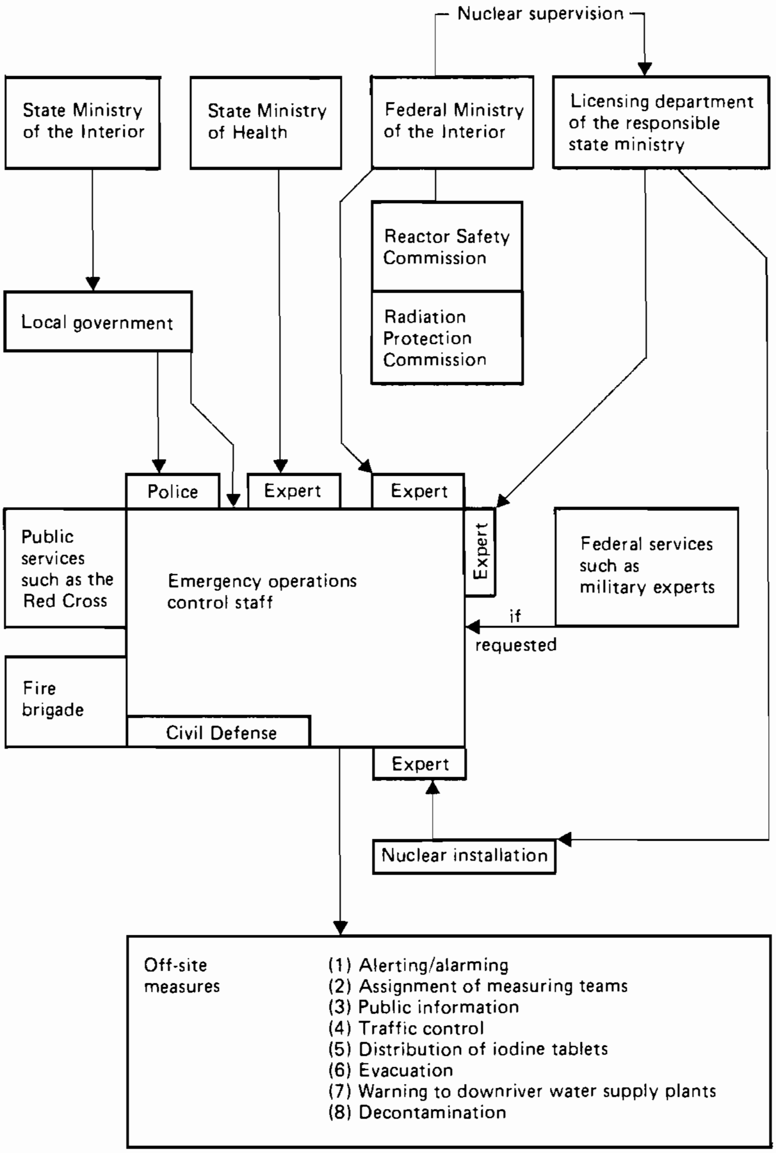

Figure 1. Organization scheme for management of a nuclear emergency in the FRG.

Communication links between the plant, the state agencies, and the Federal authorities did not prove satisfactory in a number of exercises, because the lines were frequently overburdened by numerous calls and inquiries from the press, the public authorities, and concerned private individuals. Additional telephone and telex connections and radio communication facilities are to be installed between the responsible authorities.

The Federal Ministry of the Interior has formulated the main objectives for research and development efforts in the field of emergency planning. These objectives include the classification of unexpected radiation exposures and the development of adequate countermeasures; it is hoped that this research can be applied to better evaluate possible accidents, and to improve the effectiveness, planning, and optimizing of emergency measures, as well as the organization of the best possible medical treatment.

PUBLIC INFORMATION AND ACCEPTANCE

The Ministries of the Interior of the states within the FRG have issued a brochure for public information, in which the principles of reactor safety, alarm signals, countermeasures by the emergency management authorities, means of protection, and recommendations on how to behave are illustrated and explained in simple language. This information has been distributed within a radius of 10 kilometers of each nuclear power plant and is available to any person upon request.

Speaking of only the peaceful uses of nuclear energy, nuclear accidents are almost the only threat felt by the public. In the FRG 13 nuclear power plants now in operation and 2 nuclear research centers have led to acceptance of this form of energy generation. Still, planning and construction of additional nuclear plants at other sites have caused protest or even violence. The means of ensuring steady progress in an atmosphere of confidence is information and education.

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12

AN EVALUATION OF THE NUCLEAR ALARM EXERCISE PERFORMED AT THE NECKARWESTHEIM NUCLEAR POWER PLANT

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INTRODUCTION

In the Federal Republic of Germany (FRG) both reactor owners and government authorities must take action in the event of an emergency at a nuclear power plant. The owners' responsibilities are to stabilize the reactor, to alarm the authorities, to make data pertaining to the event available in as much detail as possible, and to send a specialist to the government authorities. The authorities must ensure that the health of the population is protected and must prepare a plan of action for the very improbable case of a nuclear catastrophe.

In October 1978 a nuclear alarm exercise was carried out at the Neckarwestheim plant in Baden-Württemberg, FRG, to test the effectiveness of existing emergency plans. The Ministry of the Interior in Baden-Württemberg organized and led the exercise, in cooperation with the Ministry for Labor, Health, and Social Welfare—the government agency with special expertise in the area of nuclear problems. The president of a smaller administrative district within Baden-Württemberg, the Stuttgart Regierungspräsidium, organized and directed the emergency staff mobilized for the exercise. The counties of Ludwigsburg and Heilbronn, both adjacent to the Neckarwestheim reactor, also participated in the exercise. Also involved were several communities and private organizations, such as the nuclear power plant itself.

The goals of the exercise were

- To educate and train emergency staff;
- To study the practicality of existing catastrophe plans;
- To test the routing of alarms;
- To test communication systems; and
- To demonstrate preparedness for nuclear accidents.

THE EXERCISE

The responsible government authorities prepared the exercise carefully, in cooperation with experts from the Neckarwestheim power plant. Although a detailed script for the "emergency" was written, it was not released to the participants from the Stuttgart Regierungspräsidium. As would happen in an actual event, the emergency staff received all its messages from the plant through normal telephone channels.

During the exercise a separate evacuation plan, a special part of the emergency plan, was tested. This involved a simulated evacuation of three small villages east of the plant. The Technischer Überwachungsverein Rheinland in Cologne developed a computer program called EVAS (*Evakuierungs-Simulations-Modell* (Evacuation Simulation Model)) for this purpose. EVAS proved to be a valuable aid for planning and analyzing evacuation processes. Its range of application includes

- demarcation of the evacuation area and division of the area into subsectors,
- assignment of people from areas affected by the emergency to reception areas,
- determination of evacuation routes,
- deployment of motor vehicles,
- determination of the capacity of the emergency stations and reception centers.

About 200 invited representatives of other States of the FRG, foreign countries, and the press watched the exercise. All activities undertaken by the emergency staff were filmed and transmitted to a large screen in a nearby hall, where the observers were assembled.

The accident scenario started with a loss-of-coolant accident. Because this event alone would not cause the release of radioactivity, it was postulated that other failures also occurred; pumps and valves were assumed to fail at the same time as the LOCA, so that only 25% of the emergency cooling system was in operation. Two and one-half hours after the initiating event, a leakage in the containment was assumed to occur. According to the scenario, a great deal of radioactivity was released for four hours. Then the emergency core cooling system was brought into full operation, the leakage was sealed, and the release of radioactivity was stopped.

The first alarm call from the reactor came at 8:35 a.m. The content of the message was roughly as follows: "We have had a LOCA; no persons are hurt; there has been no radioactive release to the environment up to now; the situation is not clear; we recommend that a prealarm be set up." A prealarm calls for the emergency staff to assemble, for a radiation expert to come to the assembly room, and for a communications system to be put in place. In response to this message the president of the Stuttgart Regierungspräsidium immediately (at 8:37 a.m.) set up a prealarm. At 8:48 the emergency staff was ready for operation.

At 9:07 a second alarm call reached the emergency staff, reporting that the situation in the plant had worsened. The pressure and temperature had risen, and the possibility of a release of radioactivity could no longer be excluded. The reactor crew recommended that an alarm be called.

After a short discussion between the staff, the radiation protection expert, and a member of the reactor operation crew who had just arrived, the leader of the emergency staff decided, at 9:20 a.m., to declare a catastrophe alarm in two counties. This step meant that the following measures were to be taken:

- Determination of the area affected by radioactivity;
- Implementation of traffic restrictions and deviations;
- Distribution of iodine tablets;
- Utilization of a special siren alarm to tell the public to switch on a radio or a television and to wait for news;
- Preparation of a broadcast message;
- Preparation of evacuation as a precaution; and
- Dispatch of special police troops with measurement sets to the affected area.

Only the last measure was implemented in reality. All others were just simulated.

At about 11:00 a.m. another piece of bad news came from the reactor crew: a leakage in the containment had occurred and radioactivity was being released up a stack. After a second conference, the president decided to continue and accelerate the evacuation. By this time 60% of the population had already left the region. It was decided to set up emergency stations, where all evacuees would be registered and measured for contamination. If necessary, people could be decontaminated at such stations and could receive first aid from expert physicians. The setting up of seven emergency stations was simulated. During the same period of time many measurement results were radioed to the emergency staff.

At 3 p.m. the reactor crew announced that the release of radioactivity had been stopped. The reactor was under control, and the exercise was terminated.

EVALUATION OF THE EXERCISE

In the weeks and months following the simulated alarm all participants evaluated their actions and reactions during the exercise. They concluded that the purpose of the exercise had been successfully fulfilled, i.e., the government authorities had demonstrated their preparedness for nuclear accidents. Still, they recognized that several problems remained to be solved and certain measures needed improvement. The sections below outline the results of the evaluation for each of the goals that had been set for the exercise.

Education and Training of Emergency Staff

It would perhaps be unfair to conclude directly from the exercise that the emergency staff was well trained. After the first alarm call the emergency staff was ready for action within only a few minutes. But this was not difficult, since everyone knew the exact starting time of the exercise and what he had to do. Clearer proof of the preparedness of the emergency staff became available only some months after the exercise, as the result of a second, completely unannounced alarm exercise. The Ministry of the Interior asked the chief of operations at the Neckarwestheim power plant to initiate another alarm exercise, whenever he wished during normal working hours. When this alarm was called the members of the emergency staff assembled as quickly as they had during the first exercise a half-year before.

Assessment of the Practicality of Existing Catastrophe Plans

The exercise revealed the necessity to improve the form and convenience of some parts of the plans. It became clear that the following components of the plans should be specified in greater detail:

- The role of the radiation protection expert,
- Channels for notifying people off-site,
- The strategy for evacuation, and
- The role of emergency stations.

(1) *The role of the radiation protection expert.* When an emergency alarm is called, the Regierungspräsidium president, as leader of the emergency staff, immediately confers with all his advisers and experts. One of the most important participants in these discussions is the radiation protection expert. In the early stages of a nuclear catastrophe he is the only person who can judge the situation more or less correctly.

During the preparatory work for the alarm exercise it became clear that one man would not be able to carry out all the necessary tasks, and therefore two experts were mobilized. But even two persons proved to be insufficient to perform all the necessary work—to get an overview of the situation in the reactor and of conditions both on-site and off-site, to recommend appropriate countermeasures, and to evaluate all measurement results from the environment.

During the alarm exercise, the expert recommended that people be evacuated from three villages. This, however, could not be justified by the real situation at the time of the decision, for there was no release of radioactivity. The expert had based his decision on the only information he had, information pertaining to the bad situation in the reactor itself. Knowing that temperature and pressure were increasing, he recommended the major step of evacuation.

The Ministry for Labor, Health, and Social Welfare in Baden-Württemberg has now started to organize workshops for all radiation protection experts in the region. The purpose of the workshops is to permit the experts to become familiar with the problems of other sites, to exchange experiences, and to meet plant staff. If a catastrophe should occur anywhere, all experts should probably be brought to the site.

(2) *Channels for notifying people off-site.* Another component of the plans in need of improvement concerned the dissemination of information to people living or working in areas near the reactor. Radio stations, which operate around the clock in the FRG, were selected as the medium for broadcasting information. The plans require the broadcasts to be based on a quite universal text, now in the hands of all district government authorities. This text, supplemented by up-to-date information on evacuation routes, assembly places, and so on, is to be telexed to radio stations. This procedure was carried out during the exercise, but the supplementary text got too long; the writer tried to give too much information in just one message. This would have confused rather than informed the public. The exercise also revealed that writing the message and transmitting it by telex takes a very long time.

One solution would be to deposit the universal text with the radio stations and to transmit only the supplementary information from the government authority. Other solutions are still being discussed.

During the exercise questions were raised about means for informing people working outside in vineyards or fields. Loudspeaker cars could not reach all territory so a helicopter was sent to cover remote areas.

(3) *Strategies for evacuation.* During the exercise the evacuation posed the greatest problems. Although an evacuation should be put into effect only as a last resort, it must be carefully planned. The EVAS computer program was a big aid during the exercise, but it did not resolve the question of how to assemble enough vehicles and drivers. Large cities in the vicinity of the Neckarwestheim reactor have a great many city buses, but it is difficult to get access to them during the night or during rush hours when all buses are running. Experts assume that about one-third of the population would use their private cars in an evacuation. This is an average figure—during the night many more private cars would be available. In densely populated regions of the FRG an evacuation would proceed very slowly on any given route; thus it is very important to include alternative routes in the plans.

Another problem that surfaced during the exercise concerned people who refuse to be evacuated. Is it possible to force them? Certainly not, but in this case how are they to be supplied? Special plans are also needed to cover the evacuation of schools, hospitals, and homes for the aged.

(4) *The role of emergency stations.* The problem of emergency stations follows directly on the problem of evacuation, for all

evacuees are to assemble at such stations. Emergency stations have the following tasks:

- Registration of affected people
- Measurement of contamination
- Decontamination, if necessary
- First aid (routine injuries only)
- Classification of people by degree of exposure to radiation, i.e., those not affected; those strongly affected by radiation, who would be immediately transported to special hospitals; and those with a medium degree of exposure, who would be given a medical consultation during the following days.

During the exercise seven emergency stations were set up to process evacuees from three villages. This experience was later discussed in great detail and several conclusions were reached. The leader of an emergency station should be a specially licensed physician assisted by other physicians. All physicians practicing in the vicinity of a nuclear power plant need more information and education. All other personnel in the station should come from organizations specializing in providing protection during catastrophes.

The Routing of Alarms

The third goal of the exercise was to test alarm routing procedures. Here no difficulties could be observed. The alarm system seems to be suitable for both night and day operation. This was shown as well in several additional alarm exercises performed over the period of a year.

Communications Systems

The existing communication systems, i.e., the public telephone net, the police radio system, and telex machines did not function well during the exercise. In the case of telex connections, much time was needed to write and transmit a long text, and it was only possible to transmit letters and numbers. In the future a telecopy set will be used instead. It is quicker and permits the transmission of maps, handwritten messages, tables, and so forth. Several telecopy sets have already been installed in power stations and in the offices of government authorities. They are used every day, for example for transmitting daily status reports.

The exercise revealed that only well-trained people can use a radio to communicate successfully. Many mistakes occurred during the transmission of measurement results.

The public telephone was the communications channel used most often during the exercise. This system functioned well, although some problems did arise. Very often dialed numbers were occupied, because smaller communities have only one line. The staff at the Ministries, the Regierungspräsidium, and the reactor used numbers not known to the public, so it was not difficult to make connections. But even these numbers would be occupied or dead in a real catastrophe. The public would try to make personal inquiries, the press would rush to all telephones, and the whole network would break down. One can see this effect each day at 10 p.m., when the cheap "moonshine" telephone rate comes into effect.

To avoid a communication blackout during an emergency the government authorities must try to obtain connections to special networks, such as the police network, the electric power supply companies' network, and the military network. The electric power supply companies' network, which uses high voltage lines, seems to be especially suitable.

CONCLUSION

The reaction to the exercise among members of the public, and representatives of the press, radio, and television was fairly good. The most frequent criticism was that the exercise was prepared too well, so that it was only a show. But all participants in the exercise are convinced that they are well prepared for an emergency case. They have identified the problems and they are trying to solve them as well as possible. And they hope (in fact they are rather sure) that a real catastrophe will never occur.

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NUCLEAR ACCIDENT RESPONSE AND POPULATION PROTECTION IN THE NETHERLANDS: PHILOSOPHY, SOLUTIONS, AND PROBLEMS

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NUCLEAR ENERGY IN THE NETHERLANDS

The nuclear energy program in The Netherlands is relatively modest; there are two nuclear power plants, one at Dodewaard (54 MWe BWR, operational since 1968) and one at Borssele (477 MWe PWR, operational since 1973). It is not clear at this moment whether and to what extent there will be additions to this capacity in the future. Several nuclear power stations have been built in neighboring countries (Belgium, Federal Republic of Germany), the nearest and most important one being that at Doel, Belgium.

THE PHILOSOPHY UNDERLYING THE EXISTING ORGANIZATION OF RESPONSE TO NUCLEAR ACCIDENTS AND POPULATION PROTECTION

The Nuclear Energy Act of 1963 (Kernenergiewet 1963) broadly outlines the Government's competences and the responsibilities of the persons involved. The details of these guidelines are given in general administrative orders. One example is the Nuclear Installations Accidents Decree of 1976 (Besluit Ongevallen Kerninstallatie 1976), with the corresponding detailed Ministerial Orders concerning nuclear accident management (Beschikking vaststelling Alarmregeling 1976). These formal administrative measures are based on previous studies such as the Advice of the Health Council concerning the emergency reference levels (Ministerie van Volksgezondheid 1976b) and the report setting forth 'General Principles of a Notification and Alarm System in The Netherlands,' which was presented by the Interdepartmental Commission on Nuclear Energy (Ministerie van Volksgezondheid 1976a). The main features of the nuclear accident management system can be described as follows (Beschikking vaststellung Alarmregeling 1976):

(1) *Initiation* of the accident response is carried out by the nuclear power plant.

(2) *Definitions*. The accidents are divided into 3 broad classes, according to their consequences outside the nuclear installation site:

- Accident class 1: a gaseous radioactive release above the licensed limit is imminent or taking place, but does not exceed ten times the value of this limit.
- Accident class 2: gaseous radioactive releases greater than ten times the licensed limit are imminent or taking place, and the amount released can still be approximately estimated.
- Accident class 3: the unknown amount of radioactivity released, imminent or actual, indicates the possibility of a major catastrophe.

One of the purposes of this classification is to prevent unnecessary or even deleterious actions.

According to the Advice of the Health Council (Ministerie van Volksgezondheid 1976b), the emergency reference level has been defined as a value of the integrated individual radiation dose below which it is improbable that measures to reduce the radiation risk would be justified. The emergency reference levels are given in Table 1.

Table 1. Emergency Reference Levels of Dose recommended by the Ministerie van Volksgezondheid en Milieuhygiëne, The Netherlands (1976).

	Dose (rem)	
Organ or Tissue	Children	Adults
External Radiation		
Whole body	5	15
Skin	30	90
Internal Radiation		
Whole body	5	15
Gonads	5	15
Bone marrow	5	15
Other organs	10	30

Depending on the rate and duration of the release, meteorological conditions, the geography around the nuclear installation, and other factors, the radiation risk for a given locality can be classified as shown in Table 2.

Table 2. Radiation risk classes, which can be used to classify specified geographic areas.

Radiation risk class	Whole body dose	Thyroid dose
I	Less than 5 rem	Less than 10 rem
II	5 to 15 rem	10 to 30 rem
III	More than 15 rem	More than 30 rem

Different action phases, characterized by combinations of accident classes and accident situations, will not be discussed here.

(3) *Legal competences and responsibilities in the event of a nuclear emergency* are stated in Section VI, articles 38-44 of the Nuclear Energy Act (Kernenergiewet 1963) and can be summarized as follows:

- The Minister of Health and Environmental Protection and the Minister of Social Affairs are to shut down the installation (possibly on the request of the mayor) if there is danger to public health, and to organize countermeasures to respond to the danger.
- The Minister of Agriculture and Fisheries is to take measures to protect the health of animals, plants, and the quality of agricultural products.
- The Minister of Public Works, Waterways, and Communications is responsible for measures concerning water economics.
- The mayor has the authority to take measures immediately, subject to consultations with representatives of the Minister of Health and Environmental Protection, the Minister of Social Affairs, the Minister of Agriculture and Fisheries, and the Minister of Public Works, Waterways, and Communications.
- The provincial electricity generation company has to inform the authorities about the accident situation as rapidly as possible.

Significantly, the Nuclear Energy Act does not explicitly mention the Minister of the Interior (who is generally responsible for the police, fire brigades, Population Protection Agency, etc.) in the context of nuclear accident management regulations.

(4) *The organizational structure* for nuclear emergency response centers on five groups. Their tasks are discussed below, and the links between the groups are summarized in Figure 1.

The *Operations Steering Group* (Maatregelen Commissie) makes decisions concerning adequate measures and gives necessary orders to the available operational units. This group consists of the following persons:

- Provincial Governor;
- Director of the Radiation Department, Ministry of Health and Environmental Protection;

- Director of the Nuclear Inspectorate, Ministry of Social Affairs;
- Provincial Food Commissioner;
- Director of Provincial Public Works and Waterways;
- Mayors of municipalities facing potential radiation risk;
- Regional Inspector of Environmental Health;
- Regional Inspector of Industrial Health;
- Expert from the Ministry of Agriculture and Fisheries; and
- Expert from the Ministry of Public Works, Waterways, and Communications.

The composition of the Operations Steering Group, chaired by the Provincial Governor, guarantees that the legal responsibilities of the Ministers are executed in the most responsible and efficient way. As regards the broad-ranging power possessed by a Provincial Governor and a mayor under the Provinces Act (Provinciewet 1962) and the Municipality Act (Gemeentewet 1861), the Nuclear Energy Act operates as a *lex specialis* and overrides almost completely the powers based on the two earlier Acts.

The *Tactical Staff Group* (Tactische Staf) consists of the heads of operational units. Its task is to carry out and report on the necessary countermeasures ordered by the Operations Steering Group.

The *Technical Coordination Group* (Technische Commissie) is required to coordinate the measurements of contamination and radiation, to assess the data, to keep in contact with the nuclear installation regarding the course of the accident, and to transmit information to the Operations Steering Group. The Technical Coordination Group consists of the following governmental experts:

- Head of the Physics Laboratory, State Institute of Public Health;
- Expert from the Nuclear Inspectorate, Ministry of Social Affairs;
- Expert from the Radiation Department, Ministry of Health and Environmental Protection;
- Commander of ABC Services, Provincial Branch of the Population Protection Agency;
- Head of the Central Weather Service, Royal Netherlands Meteorological Institute;
- Expert from the Ministry of Agriculture and Fisheries.

The Operations Steering Group, the Tactical Staff Group, and the Technical Coordination Group convene and operate in a common sheltered site.

Data collection groups are required to carry out measurements of radiation and contamination levels. Trained personnel, operating four mobile measuring units, are to follow one or more preplanned routes and collect data at agreed points. The actual routes are routinely checked and, if necessary, modified.

A *Back-up Unit*, located at the responsible Ministry, has the task of communicating with the media, politicians, and so forth.

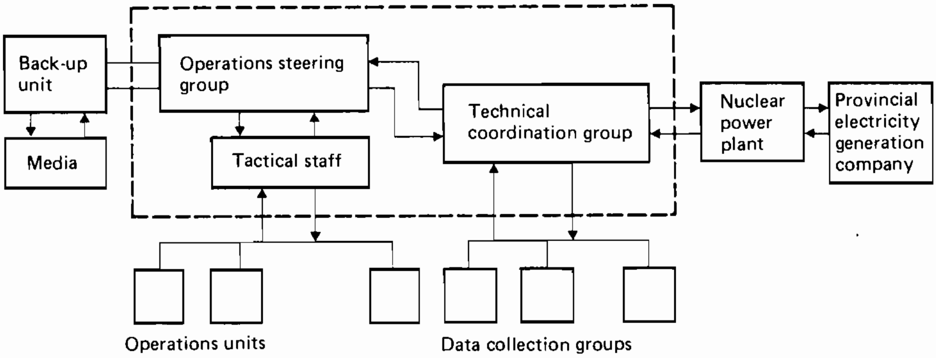

Figure 1. Organizational scheme for emergency management of nuclear accidents in The Netherlands.

(5) *Notification* concerning an accident is initially carried out by the nuclear power plant. In the case of a Class 1 accident, the plant transmits a message to the local Mayor, to the Nuclear Inspectorate within the Ministry of Social Affairs, and to the Regional Inspector of Environmental Protection. In the case of a Class 2 accident, the message is initially transmitted to the local mayor, the Nuclear Inspectorate, the Radiation Department, and the Regional Alarm Centre. The Alarm Centre then passes the message to about 25 receiving points, such as central, provincial, and local authorities, services, and institutions.

PRACTICAL EXPERIENCES AND RECENT DEVELOPMENTS

It is probably a truism to say that nuclear accident response and population protection are characterized by a lack of practical experience. Even the TMI accident has only partly changed this situation, since only low or negligible off-site releases of radioactivity occurred during that accident. This lack of practical experience leads to the questions of the motivation of the agencies involved in nuclear accident response and the importance of exercises in stimulating preparedness.

Members of the Operations Steering Group and the Technical Coordination Group are specialists or leaders whose main responsibilities do *not* concern nuclear accident response planning and management. In a small country like The Netherlands, the relatively limited contingent of nuclear radiation and emergency management specialists are normally busy with a huge number of day-to-day problems—problems that arise with a higher frequency than serious nuclear accidents. So one problem can be formulated as a question of motivation within a limited pool of human resources.

The low frequency of nuclear accidents, combined with limited motivation, naturally enhances the importance of exercises in nuclear accident response planning. Of course, exercises can be very different in scope, both in breadth (numbers of people involved) and depth (degree of simulation). So far, the regular exercises and drills that have been performed in The Netherlands have had the following objectives:

- To raise the level of motivation and consciousness among the participants;
- To test and improve the response time of the participants;
- To check the adequacy (both in qualitative and quantitative terms) of the communication lines;
- To measure the time needed to coordinate the different decision making and operational units;
- To measure the time necessary to collect and transmit data, and then evaluate them in the Technical Coordination Group;
- To assess the work of the Operations Steering Group.

Within the limited scope of objectives, the four exercises executed so far in The Netherlands have provided valuable results, showing a satisfactory picture of preparedness for the tested sections of the emergency organizations.

The TMI accident has focused renewed public and professional interest on nuclear accident response management. In The Netherlands this has led, in combination with the results of exercises and relevant experience in other countries, to a review of the existing philosophy and organization for protecting the public. As a preliminary conclusion it may be stated that a need for very radical changes was not found, but improvement seems to be desirable or possible in a number of fields. These will be discussed in the following sections.

Dose Estimates

Estimates of received or projected doses to the population can be based on emission data from nuclear power plants or on off-site measurements. Both methods must be available, although the use of emission data is, in principle, preferred because it gives more immediate information, because the information, if combined with adequate meteorological data and evaluation methods, is more complete and reliable, and because it is more cost-effective.

The Bavarian Landesamt für Umweltschutz (Provincial Office for Environmental Protection) has acted in accordance with this philosophy; it has installed its own emission measuring instruments in nuclear plants and connected them remotely to a powerful data acquisition and processing system (Eder 1977). In The Netherlands, it was realized early on that in addition to instrumentation suitable for normal operation, extra instrumentation is needed that can function under accident circumstances, both from the point of view of shielding and of measuring range requirements (Bősnjaković and Bogaerde 1978). The installation of this extra instrumentation to measure emissions of noble gases and radioactive iodine has been under way since 1977. The TMI accident has confirmed that emission instrumentation deserves to be reviewed with high priority (USNRC 1979).

The second method of measuring population doses, i.e., using off-site instrumentation, can rely on mobile or stationary units. As mentioned above, four mobile measuring units are already in operation in The Netherlands. The existing net of stationary measuring points around the Dodewaard power station is shown in Figure 2. Currently the following extensions to off-site monitoring capabilities are being studied: addition of an airborne measurement platform; extension of off-site gamma-radiation monitoring capabilities; and extension of off-site iodine measuring capabilities, either mobile, stationary, or both. Off-site monitoring capabilities are of utmost importance for determining individual and collective doses after an accident, as well as for routine surveillance.

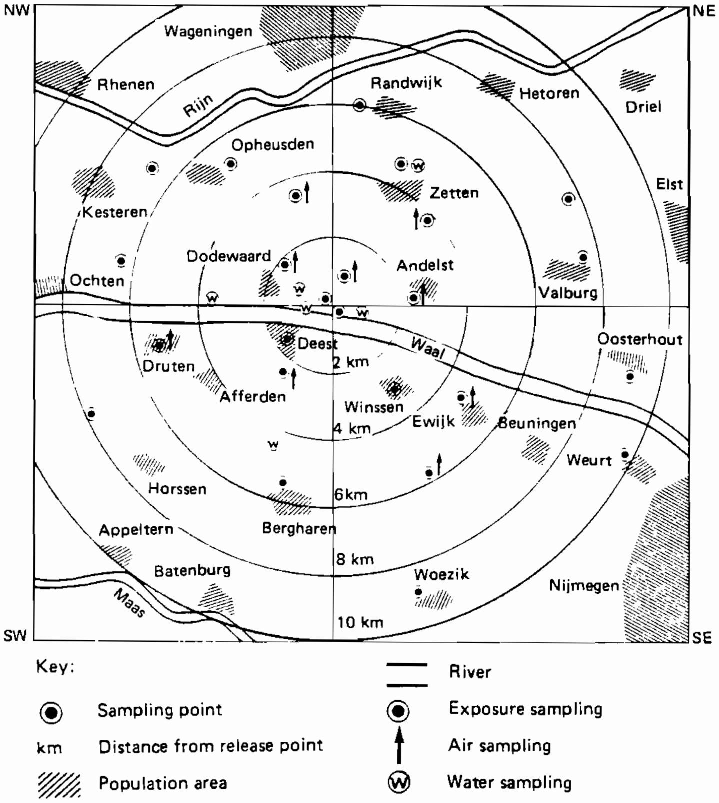

Figure 2. Off-site monitoring points around the Dodewaard nuclear power plant in The Netherlands.

Data Transmission and Lines of Communication

As far as exercises are concerned, the existing means of communication—cable and radio links, and a number of reserved telephone lines—have proven to be sufficient. The availability of a considerable number of participating specialists is improved by placing radio equipment in their private cars. The congestion of telecommunication networks, which is rather probable in the case of a real accident, cannot be easily simulated by exercises. Therefore, an extension of the number of reserved telephone lines (which would remain unaffected by a general telecommunications jam) is under consideration. All the details of the emergency telecommunications system, such as actual telephone numbers, are not published, to prevent possible misuse.

Notification of the Population, Vertical and Horizontal Evacuation Capabilities, and Other Protective Measures

The Swiss authorities have developed an integrated, internally consistent concept of protective measures for the population, based on the following elements (Eidgenossisches Amt für Energiewirtschaft 1977):

- Notification of the population as directly as possible, using local sirens and a central radio station;
- Emphasis on vertical evacuation during the first critical hours, relying on existing (mainly private) shelters;
- Horizontal evacuation only under exceptional circumstances, such as in the case of high-level ground contamination.

All these elements are present in Dutch protective measures for the population, but probably to a different degree. Because of differences in soil properties and traditions, there are fewer shelters in private houses. As well, the construction of shelters to protect against wartime nuclear explosions has had a different history in the two countries, due to different political attitudes. Additional studies and improvements are certainly desirable in the area of population protection, especially with respect to the effectiveness of population notification procedures.

The questions of the use of emergency planning zones and the administration of stable iodine have still not been resolved in The Netherlands. The Kemeny Commission reported rather negatively about the usefulness of emergency planning zones (President's Commission 1979), but the zone principle has been incorporated in a number of European population protection concepts (Eidgenossisches Amt für Energiewirtschaft 1977; Bundesministerium des Inneren 1975).

The question of stable iodine distribution is also not fully resolved, even though the Kemeny Commission and the US Administration seem to take a rather positive stance (President's Commission 1979; US Department of Health, Education, and Welfare 1978). It seems that in European countries the view predominates that for logistic reasons alone, administration of stable iodine during a short, acute nuclear accident would only be justified for a relatively small, critically exposed population group, say up to 10,000 persons. This argument is not necessarily valid for accidents of longer duration. In addition, some minor medical contraindications have been reported and should be taken into consideration (Jongkees and Brouke 1975). Finally, one of the most important considerations is our conviction that dose reduction due to iodine tablets is of little use, if compromised by additional external and internal doses stemming from iodine distribution requirements.

Another controversial question relates to the risks, radiological and nonradiological, connected with horizontal evacuation (Haus and Sell 1974). According to the Kemeny Commission, these risks may have been overestimated in the past. In this context it may be worthwhile to study the chlorine gas accident near Toronto where, in November 1979, more than 200,000 persons were evacuated within a few hours (Neue Zürcher Zeitung, 14 November 1979).

Strengthening of the Organizational Structure, Improving the Preparedness of Local Authorities, and Clarifying the Role of the Nuclear Plant Operator

At the central authority level, it would be desirable for national organizations like state police, fire departments, and the Public Protection Agency to play a more active role. The operational execution of steps and measures necessitated by nuclear emergencies is mainly the task of provincial and local authorities. The planning of their task will be performed according to an expected new law concerning municipal emergency plans (Wetsontwerp 1977). The task will eventually require detailed plans for hospitals, industrial plants, schools, and so forth. The elaboration of municipal plans will naturally require cooperation with nuclear and radiation specialists from the central authorities.

An interesting question is whether the role and responsibility of the nuclear power plant for off-site nuclear accident response should be increased. This is the case in a considerable number of countries (see for instance Matthews and Pepper 1981). There are two strong arguments in favor of the expansion of the power plants' role, namely the "polluter pays" principle, and the availability of high-quality expertise in the plant. Arguments against it are that the government authorities should not transfer their responsibilities to a third party, and that the plant experts are needed to deal with events in the plant itself. The TMI accident has shown that the number of specialists required is considerable. Thus an increase in the number of available specialists should be aimed at, both through national efforts and through international agreements.

International Cooperation

A system of coordination has existed between The Netherlands and Belgium since 1975. This ensures that competent authorities in the neighboring country can be quickly contacted and alarm given if required, should there be an emergency in the nuclear installations at Borssele, Doel, or Mol. At the moment, negotiations are being conducted to elaborate and refine the existing regulations. In particular, a Ministerial Order concerning the protection of the Dutch population in the vicinity of the Doel power station is in the final stage of preparation.

An agreement regarding the exchange of information and consultation with respect to nuclear projects close to the joint frontier was concluded in a Memorandum between the Dutch and German authorities in 1977 (Ministerie van Volksgezondheid - Bundesministerium des Innern 1977). A Dutch-German Commission has been established to discuss all matters of mutual interest in the nuclear energy sector. It is empowered to appoint working parties for specific purposes. In this context, one working party has been appointed to treat problems of nuclear accidents. Some other questions to be addressed include the following:

- Will it be possible to evacuate people across a frontier?
- Will there be disagreement due to differences in Emergency Reference Levels or different judgments about meteorological conditions?
- Will assistance be given by neighboring countries?

One may envisage transfrontier exercises of communication facilities and emergency teams.

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14

ASPECTS OF ACCIDENT MANAGEMENT AT NUCLEAR POWER PLANTS IN THE USSR

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INTRODUCTION

In many countries nuclear power is being successfully used for the production of thermal and electrical energy and the nuclear energy industry is becoming an independent branch of the economy. According to estimates given at the Tenth World Conference on Energy (Istanbul, 1977), nuclear-based electric energy may account for 45% of world energy production by the end of this century. The program of economic development for the USSR, as adopted by the Twenty-fifth Congress of the Communist Party of the Soviet Union, envisaged the construction of nuclear power plants in the European sector of the USSR.

Production of thermal and electrical energy at a nuclear power plant involves the generation and accumulation of a large amount of radioactive material. This creates a potential for radiological exposure of plant personnel, the general population, and the environment in the case of an accident. Safety requirements have been set forth for nuclear power plants to mitigate this danger. An examination of the practical operating experience of nuclear power plants in the USSR shows no cases of irradiation that exceed the maximum permissible dose. Technical measures adopted during the construction of an atomic power plant provide a framework for the safe operation of plant equipment.

ACCIDENT CLASSIFICATION

Safety requirements should ensure that any component failure can be fully controlled, while the operational status of the facility is maintained. In the event of a failure, any effect on plant personnel, the general population, or the environment should be prevented (Sidorenko *et al.* 1977).

The problem of the "potential danger" of accidental exposure of the general population became apparent in the early days of nuclear energy and still exists. This concern led to the concept of a "maximum rated accident" (MRA), defined by its radiological consequences. Safety devices developed to respond to a MRA are designed to localize any damage to the core and to protect employees. When the scale of an accident is greater than an MRA, such safety measures may not be effective; here the concept of a "maximum possible accident" (MPA) must be considered. Although an MPA is characterized by large-scale radiological consequences, its probability of occurrence is so small that no technical mitigating measures have been specified. The siting of nuclear power plants 25 to 40 km from cities, combined with the planned accident response measures discussed below, ensures the safety of the general population in the case of such an accident.

The planning of safety measures is thus based on a classification of accidents in terms of their radiological consequences. The scale of an accident is determined by the quantity of radioactive materials released, primarily from the reactor core. The amount of radioactivity released outside the plant depends upon the reliability of safety systems.

Accidents connected with losses of coolant from the primary circuit have been classified in the following way (Atomenergo 1978):

- Category I: accidents involving fuel melting;
- Category II: accidents involving depressurization of fuel elements without fuel melting;
- Categories III-V: accidents involving a failure in the primary circuit and loss of coolant, without depressurization of fuel elements.

In the case of Category I or II accidents, the reactor should be scrammed in order to prevent the increase of vapor pressure in the intact elements and the release of fission products inside the plant. Accidents in Categories III-V are characterized by the localization of radioactive products in the fuel elements.

Three types of radiological consequences of accidents may be distinguished: local (occurring inside the plant); regional; and general. Radioactive consequences of local accidents are determined by the structure of the power plant; radiation doses to employees might be several times higher than those experienced under normal operating conditions. Regional accidents are characterized by radioactive releases within the region where the power plant is located. In the case of a general accident, the level of irradiation and environmental contamination violates the existing USSR environmental standards for the operation of nuclear power plants.

SAFETY MEASURES

Only general accidents, including the concepts of "maximum rated accident" (MRA) and "maximum possible accident" (MPA), are considered in the planning of safety measures. The maximum release of radioactive inert gases and aerosols (including radionuclides of iodine) permitted for normal operating conditions of a power plant may not be more than five times higher than the admissible standardized daily release (ASR).* Any release in excess of this maximum amount should be compensated for by lower releases during the subsequent time period (Atomnaya energiya 1979). It should be mentioned that the operational standard for a nuclear power plant is lower than the ASR. The statistical mean of radioactive releases determines the operational standard.

In the case of a maximum possible accident, planned safety measures are taken when the expected equivalent whole body dose exceeds 25 rem or when the dose to the thyroid (by inhalation of radioactive iodine) is expected to exceed 150 rem for adults and 75 rem for children (Ministry of Public Health of the USSR 1971).

The safety precautions include the following measures:

- Temporary shelter;
- Limited stay in the open air;
- Decontamination of skin and clothing;
- Limited consumption of contaminated food;
- Iodine prophylaxis.

Temporary evacuation of the population is planned if the whole body dose is expected to exceed 75 rem. Children are to be evacuated when the forecast dose to the thyroid is greater than 225 rem. Hospitalization is planned for those who have received whole body doses greater than 100 rem or thyroid doses greater than 400 rem (adults) or 200 rem (children) (Turkin *et al.* 1977).

Integrating dosimeters are used to determine the gamma radiation dose to the population. These are placed in different locations around the nuclear power plants. Continuously operating dosimeters make it possible to monitor the development of an accident.

ACCIDENT MANAGEMENT ORGANIZATION

Accident management activities are based at a coordination center set up in the power plant, and involve both plant personnel and government authorities. The center is divided into sections, each attending to one of the following problem areas:

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*A standardized release has been normalized according to the installed capacity (GWe) of the nuclear power plant.

- Constant surveillance of the operating conditions of the power plant;
- Radiation control;
- Dosimetric inspection of the territory around the plant and the environmental protection zone;
- Protection of the population and provisional evacuation, if necessary;
- Medical aid for the population and plant personnel, including iodine prophylaxis.

The source of information about the development of the accident, the form and content of the information, and the method used to provide the information vary according to managerial level, as indicated in Figure 1. Many types of information are needed for decision making about necessary safety measures, and this must be provided within the short response times required

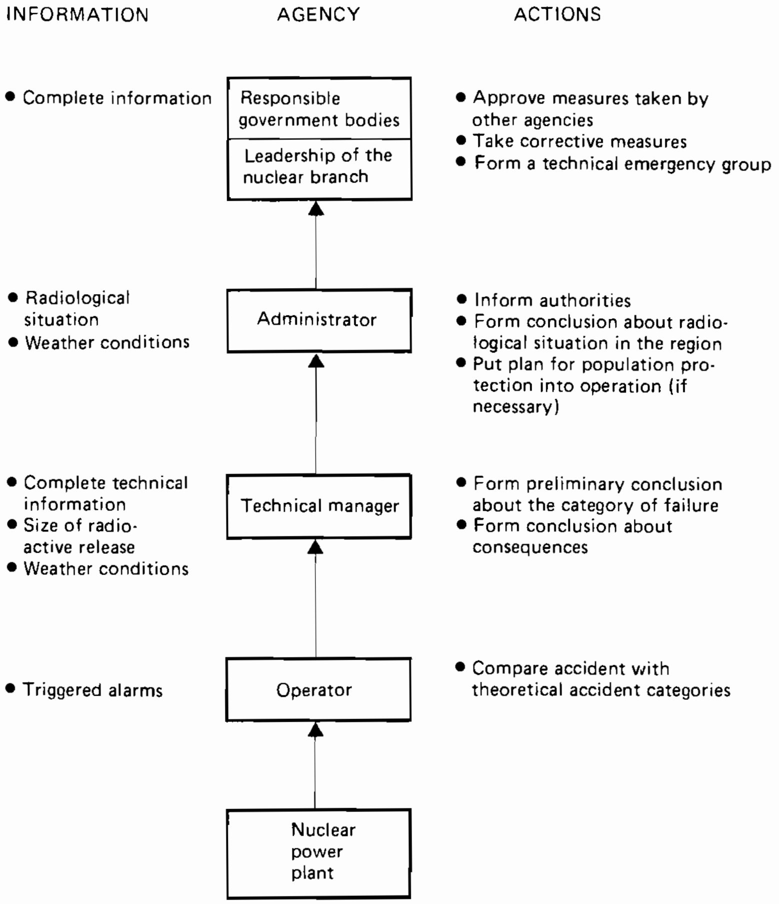

Figure 1. Hierarchies of information needs and actions for accident management, by managerial level.

in an accident situation. The hierarchies of types of information, responsible agencies, and the possible actions associated with the information are sketched in Figure 1.

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15

THE FRENCH APPROACH TO MANAGEMENT OF LARGE NUCLEAR ACCIDENTS

A. Teste du Bailler
Electricite de France

Before dealing with the French aspects of management of nuclear accidents, it may be useful to summarize the highlights of the French nuclear program. Because of a severe lack of natural resources in France, plans have been made to generate a large amount of electricity from nuclear plants. As of November 1, 1980, the French nuclear expansion program included twelve 900 MW pressurized water reactors (PWR) in operation, four under commissioning, and eighteen under construction. Thirty-six 1300 MW PWRs were under construction or in planning phases. In addition, a 1200 MW liquid metal fast breeder reactor is being built in cooperation with Italy and Germany.

The entire nuclear fuel cycle is considered within the French nuclear program, including the mining and enrichment of uranium, manufacturing of fuel elements, and, above all, the reprocessing of nuclear waste at La Hague. In keeping with the consolidated nuclear program, all those working in the nuclear field—regulators, operators, and suppliers—are fully informed about procedures for the management of nuclear accidents.

Since 1958 a special attachment to each government department's emergency organization plan for nonnuclear accidents has specified protective measures to be taken in case of civil or military nuclear accidents in France. More recently the Ministry of the Interior called for the preparation of another set of documents—specific plans for emergency intervention (plans particuliers d'intervention et de secours (PPIS)) for each plant. These plans are more complete and more accessible to the public than the special attachments discussed above. Also, the utilities have to prepare on-site emergency guides (plans d'urgence interne (PUI)), which define all the procedures for reducing the consequences of any nonnuclear or nuclear accident. These documents are prepared case by case, plant by plant; they depend on the local conditions, population, geology, industry, and so forth.

Available emergency guides provide only a list of communications lines and addresses of hospitals and shelters. So far, regulatory agencies have chosen not to decide in advance, on the basis of hypothetical accidents, which countermeasures are to be used. In their opinion the initial major problem is *preventing* an accident instead of planning how to deal with one. As was said in the Kemeny Commission report, it is more useful to work on "what is" than on "what if" questions.

The TMI experience has called our attention to the need for improvements in the construction and operation of a plant. Some projects are underway in France that aim at improving operating conditions in nuclear plants; these include a new display for control rooms, training and evaluation of performance on simulators, and research on human behavior in normal and abnormal situations.

From a personal and philosophical point of view, insofar as I am in charge of the operation of nuclear facilities, I think it is better to plan for decisions about off-site countermeasures to be made in the course of an accident, rather than to try to make those decisions a priori. I also think that it is fundamental to have a certain level of public acceptance (which is sooner said than done). This is the first requirement for good preparedness for an emergency situation, and also for limited or general training of the public. An emergency guide for the public has been approved by local authorities, and some parts have been discussed with working groups, including ecologists and environmentalists. In spite of difficulties, "relentless truth-telling," as Mr. Green has said (see Chapter 16) is important for a comprehensive approach to accident management. A public who has agreed to the nuclear alternative and assumed all associated risks will be more cooperative and understanding if an accident should occur.

IV. BROADER ISSUES

Nuclear accident preparedness and management means much more than preparing plans and carrying out exercises. This Section brings together three papers that address some broader considerations, which touch on the implications of the rarity of nuclear accidents.

The first paper looks at nuclear safety in the context of the political process that has led to the development of nuclear power. The rarity of nuclear accidents creates special problems for the political process, for it requires the management of a societal risk in the absence of substantial, concrete accident experience. The second paper looks at the role of the operator in nuclear accident management. Again, the rarity of such accidents creates special problems, as each operator must maintain preparedness for an event that is extremely unlikely to occur while he is on duty. The third paper focuses on legal liability and compensation in the case of nuclear accidents in the US, a problem compounded by the lack of precedents and accurate estimates of the effects of the accidents.

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IMPLICATIONS OF NUCLEAR ACCIDENT PREPAREDNESS FOR BROADER NUCLEAR POLICY

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The fact that there was a Three Mile Island (TMI) accident has in itself significant implications for broader nuclear policy, because of the connotation that nuclear power is less safe than previously believed. To the extent that TMI is perceived as requiring new, additional, and more realistic measures to prepare for nuclear accidents, these implications are amplified because preparedness stands as a strong, continuing reminder of the accident potential. The implications for broader nuclear policy will, of course, vary, depending upon the particular conditions in each country. The range of such conditions is too broad to permit generalization, so my discussion will relate primarily to the situation in the United States.

HISTORICAL PERSPECTIVES ON THE NUCLEAR POWER INDUSTRY

The history of preparedness for catastrophic accidents in nuclear power plants in the United States should be considered in light of the larger history of the nuclear regulatory authorities' efforts to nurture and protect the nuclear power industry. A brief recounting of this larger history is appropriate.

As is well known, the central piece of legislation in this history was the Atomic Energy Act of 1954. It abolished the early government monopoly over nuclear power technology and opened the door to private development of nuclear power in the United States. Despite the monumental significance of this legislation in thrusting the country onto a course of primary

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reliance on nuclear power to meet long-term electricity needs, there was no public discussion of or debate on the risks inherent in the technology. Although there were no less than thirty explicit references in the 1954 Act to "health and safety of the public," the legislative history is devoid of any discussion of the nature and magnitude of the potential threats to health and safety. In the mid-1950s there seemed to be broad public acceptance of the potential benefits of the atom, with no apparent apprehension of its risks. Indeed, the tranquility of the public was so great that the Atomic Energy Commission did not hesitate to publish the Brookhaven Report (USAEC 1957), with its box-car estimates of fatalities (as many as 3400 within 15 miles), injuries (as many as 43,000 within 45 miles) and property damage (as much as 7 billion dollars), to justify enactment of the Price-Anderson Indemnity Act.

Within the next few years, however, mounting concern about nuclear safety—at least in certain sectors of the population—led the atomic energy establishment to erect a defensive shell. The belief that the public was too unsophisticated to make a realistic appraisal of the risks of nuclear power, and that candid discussion of the risks would produce an irrational response that would slow the growth of nuclear power, led to a new tacit policy of trying to convince the public that the risks of a catastrophic accident were essentially hypothetical and, in any event, virtually zero.

Thus, when the extension of Price-Anderson was under consideration in 1965, and an updating of the 1957 Brookhaven Report was commissioned, the new report was suppressed to avoid stimulating the fears of the public and providing new ammunition for the antinuclear movement. By this time, it had become fashionable, if not imperative, to refer to the possibility of an accident only with qualifying adjectives and adverbs that would emphasize the remoteness of the possibility. For example, in the report of the Joint Committee on Atomic Energy (1966) on legislation providing for waiver of certain legal defenses in litigation arising out of nuclear accidents, a major accident was variously characterized in this single document as "extremely remote," an "exceedingly remote contingency," "low probability," an "extremely unlikely event," a "remote possibility," a "highly remote contingency," a "highly improbable event," and "exceedingly remote."

Consistently with this approach, it was Atomic Energy Commission (AEC)/Nuclear Regulatory Commission (NRC) policy to spare the public in the vicinity of nuclear power plants knowledge of the potential destructive impact of a nuclear power plant catastrophe. Although licensing regulations required discussion of various accident scenarios, the consequences of a catastrophic accident did not have to be discussed because of the asserted extremely low probability that such an event would occur.

THE HISTORY OF PREPAREDNESS FOR NUCLEAR ACCIDENTS

In the context of this general history, I can now turn specifically to a discussion of the background of preparedness for nuclear accidents. Since the early years following enactment of the 1954 Atomic Energy Act, the regulatory scheme for dealing with possible major accidents has rested on two separate approaches: site geography and emergency planning.

With respect to siting considerations, Part 100 of Title 10 of the United States Code of Federal Regulations—promulgated by the AEC in 1962 and continued in effect by the NRC—establishes Reactor Site Criteria. These require each reactor site to be within an exclusion area, which in turn must be within a Low Population Zone (LPZ). The size of both areas is defined in terms of the radiation dose that an individual would receive at the boundaries as a consequence of a postulated release of fission products resulting from a design basis accident. The LPZ is further defined as:

> "the area immediately surrounding the exclusion area which contains residents, the total number and density of which are such that there is a reasonable probability that appropriate protective measures could be taken in their behalf in the event of a serious accident." (United States Code of Federal Regulations, 1962b).

Such "appropriate protective measures" would, of course, include evacuation and provision of shelter.

Thus, the first line of preparedness for major accidents has been the principle of siting a nuclear power plant at a site where the size and population characteristics of the LPZ would permit evacuation or sheltering of the population in the event of an accident that threatens public health or safety. It should be observed, however, that this approach involves some inherent limitations; Part 100 is relevant only to the siting determination and does not involve mechanisms which would be applicable after issuance of the license. Thus it does not have mechanisms for preserving the population and other characteristics of the LPZ required for the siting determination in the first place. It is entirely possible that during the license term the population in the LPZ could double or triple, and land use patterns could change so much that evacuation or sheltering of the population becomes infeasible.

Under Part 100 the minimum size of the LPZ is dependent upon radiation doses at its outer boundary. Thus the size of the LPZ can be reduced if engineered safeguards are incorporated to reduce the quantities of fission products that will be released from the containment under credible accident circumstances. The manipulation of the size of the LPZ through use of engineered safety features has been translated into judgments about the number of people who would have to be evacuated in the event of an accident. For example, in a 1974 decision the Atomic Safety and Licensing Appeal Board noted, remarkably, that a reduction in the size of the LPZ "will make it unnecessary to evacuate persons formerly within (before the reduction of the size of the LPZ), but now outside that zone." (USAEC 1974). One can interpret this attitude towards potential evacuation more as resembling a mathematical game than as reflecting a real concern with the protection of people. This is particularly the case when it is recognized that the engineered safety features may not work as advertised.

With respect to the second approach, i.e., actual emergency planning, the AEC and then the NRC have always at least nominally required consideration of measures for protecting the public in the event of a radiological emergency. This requirement is spelled out in Appendix E to 10 CFR Part 50, which was originally adopted in December 1970. Appendix E distinguishes between consideration of emergency planning at the construction permit stage and the operating license stage. At the construction permit stage, there is no need to present detailed plans, rather only enough information "to show that (appropriate protective) measures (e.g., evacuation) are feasible" (USNRC 1977a). At the operating license stage, the actual plans for coping with emergencies (although not the details of the plans or the details for their implementation) must be presented to an extent sufficient to demonstrate "reasonable assurance that appropriate measures can and will be taken in the event of an emergency...." (United States Code of Federal Regulations 1962a).

In reality, however, AEC/NRC took a lackadaisical approach to implementation of emergency planning requirements. It is not necessary for present purposes to elaborate on the manifestations of this approach; it suffices to note that both the General Accounting Office and Congressional committees have found emergency planning to be woefully inept and inadequate (Comptroller General of the United States 1979; House Committee on Government Operations 1979).

The major factor underlying the NRC's approach was the premise that careful siting plus appropriate design-engineered safeguards constitute primary and adequate protection—emergency planning being only a secondary, contingency add-on for the case of the highly unlikely accident situation (Federal Regulation 75169, 1979). This premise was in turn conditioned and driven by the concern that increasing emphasis on emergency planning would unduly alarm the public and contribute to the antinuclear movement. This concern was not ill-founded. AEC/NRC, having boxed itself into the myth that the probability of a serious accident was so vanishingly low that it need not trouble any rational person, could not easily treat such an accident as sufficiently credible to warrant highly visible emergency plans without loss of face and credibility.

Moreover, although the applicant had the burden of meeting AEC/NRC requirements for emergency planning as a condition for obtaining the construction permit or operating license, the efficacy of emergency plans was obviously dependent upon the planning and cooperation of State and local agencies, which were not subject to Federal jurisdiction. Since any effort by AEC/NRC to work with State and local agencies to develop more adequate emergency plans would heighten public awareness of the possibility of an accident, AEC/NRC were generally quite willing to issue licenses with no real inquiry into the adequacy of such plans. A related factor, of course, was the AEC/NRC concern that State and local governments might exercise a de facto veto over nuclear power plants through refusal to develop adequate emergency plans.

As a consequence, only pro forma consideration was given to emergency planning in the licensing process. Consideration was perfunctory at best at the construction permit stage, so that any real consideration of the adequacy of the plans would take place only after hundreds of millions of dollars had already been invested in construction at a given site. Moreover, through a strange process of reading Part 100 and Appendix E of Part 50 together, the scope of consideration of emergency planning in licensing proceedings was narrowed by the interpretation that the applicant had no responsibility for emergency planning beyond the perimeter of the LPZ (USNRC 1977b).

These approaches to preparedness for major accidents reflected the essentially probabilistic approach to analysis of potential accidents that has pervaded nuclear power licensing for 25 years. The mythology has been that a technological system designed to accomplish something will accomplish it. The compounding of such optimistic assumptions leads to estimates of an extremely low probability of a significant accident occurrence. When the potential consequences (even if a very large number) of such an accident are discounted by the vanishingly small probability of the occurrence that is produced by optimistic assumptions, the laws of mathematics yield a very low product representing total risk. This mythology has produced the proposition that a Class 9 accident (in which the engineered safeguards are assumed to be ineffective) need not be considered in licensing actions because, although the consequences could be "severe," the probabilities of such an occurrence are so low.

THE IMPACT OF THREE MILE ISLAND

Three Mile Island dealt a massive blow to this way of thinking. It became quite clear that human beings are not sufficiently omniscient and infallible to foresee all adverse events that might occur and to establish design features that would reliably forestall and contain such events. What previously had been regarded as incredible suddenly became stark reality. Indeed, in the eyes of the NRC staff the TMI event was a Class 9 accident, an accident previously thought to have such a remote probability that it did not warrant consideration. Despite the NRC's long-standing insistence that an applicant's obligations for emergency planning stopped at the boundary of the LPZ, at the height of the TMI crisis the agency considered measures for protecting the public at distances ten times greater. As the NRC itself has recently stated in the bland prose of a self-protective bureaucracy that only three months earlier had expressed essential satisfaction with the status quo:

> The Commission's perspective was severely altered by the unexpected sequence of events that occurred at Three Mile Island. The accident showed clearly that the protection provided by siting and engineered safety features must be bolstered by the ability to take protective measures during the course of an accident. The accident also showed clearly that on-site conditions and actions, even if they do not cause significant off-site radiological consequences, will affect the way state and local entities react to protect the public from dangers, real or imagined, associated with the accident" (Federal Regulation 75169, 1979).

In accordance with these realizations, the NRC is now proposing new rules (Federal Regulation 75167-174, 1979) that require NRC concurrence in State and local emergency plans as a condition of operating licenses; as well, the new rules require an extension of emergency planning considerations far beyond the perimeter of the LPZ.

Although the NRC had previously defended its policy of not providing emergency planning information to the general public (Gossick 1978), the proposed new rules would require dissemination to the public of basic emergency planning information, including the possibility of accidents, potential human health effects, and contemplated protective actions. On one hand, if the requirement is to be meaningfully implemented, dissemination of such information will hardly allay the apprehensions of those who already fear nuclear power and may, indeed, win new converts to the antinuclear camp. On the other hand, it is self-evident that there cannot be effective preparedness for a serious accident unless the planners and those who will be affected by implementation of the plans have the essential facts and are encouraged to view the possibility of a catastrophic accident seriously rather than as a light-hearted hypothetical exercise.

Meaningful preparation for catastrophe can be undertaken without frightening people who may be affected. We are all familiar with life-boat drills on ocean liners and flight attendants' routine emergency instructions at the beginning of commercial air flights. Most recipients of such instructions seem to welcome these briefings; they listen attentively and do not appear to become apprehensive. Similarly, telephone directories in Hawaii offer prominent instructions on actions to take in the event of a tsunami, and San Francisco phone books offer similar advice with respect to earthquakes. These instructions do not seem to generate any perceptible panic on the part of either residents or visitors.

However, a significant distinction can be drawn between the case of aircraft and ocean liners on the one hand, and nuclear power plants on the other. It is self-evident that serious accidents involving aircraft and ships (and dams, bridges, etc.) will occur and can have catastrophic consequences (at least for the persons immediately affected). Everyone knows, as a matter of common wisdom and experience, that human or technological failings, and Acts of God, can produce highly destructive events in these cases. In contrast, the circumstances that could lead to a catastrophic nuclear power plant accident are much more complex and the nature of the catastrophe cannot be well understood by the general public. No one would believe assurances that an aircraft cannot crash, that a ship cannot sink or catch fire, or that a dam or bridge cannot collapse; but the public has been willing to accept comparable assurances that a nuclear power catastrophe will not occur because technological systems have been installed that will override human error, mechanical "bugs," and Acts of God. Perhaps the most important long-term consequence of TMI is the destruction of the credibility of nuclear experts who have been offering such assurances for 25 years.

In order for emergency planning to be meaningful, it is necessary to engage the attention of the public that would be affected in an emergency situation. The full potential dimensions of the catastrophe for which the emergency plans are developed must be disclosed with sufficient candor and vigor that the public will not regard it as an idle hypothetical exercise. To do this, however, is to vividly remind the public that nuclear power is an extraordinarily hazardous technology—a confession that may lead many members of the public to oppose and reject its further use. But the fact that a technology is extraordinarily hazardous does not mean that the risks cannot be drastically reduced through appropriate design, operation, and maintenance or that the risks are unacceptable. The crucial question is the extent of public confidence in the officials who determine how safe is safe enough.

A recent study (Slovic *et al.* 1980) has shown that when the general public assesses risk, much more weight is given to the quantum of potential adverse consequences than to the extremely low probability of an occurrence that will produce those consequences. In my opinion, the nuclear establishment has low credibility among members of the public because it has used the unnatural strategy of attempting to persuade the public that the low probability of an accident makes nuclear power acceptable; the potential catastrophic consequences associated with the occurrence of an accident have been downplayed. This creates the impression that there is something to hide, and nothing contributes more to a credibility gap than the perception that a public agency is concealing something—particularly when there are so many other overt manifestations of extraordinary risk, such as the Price-Anderson Act. A major Achilles' heel of the nuclear power establishment in the United States has been the effort to persuade the public that it need not fear a nuclear power plant catastrophe, while at the same time catering to industry's fear of such catastrophe through continuing extension and refinement of the Price-Anderson Act.

If nuclear power in the United States is to survive TMI, it is essential that emergency planning be linked with a broad program of candor designed to increase the credibility of the nuclear regulatory institutions. TMI provides the opportunity for appropriate *mea culpas*, in the form of a confession that for the most laudible of motives (i.e., to protect against emotional and irrational responses that might cause the vitally necessary technology to be rejected), we have attempted to persuade the public that a catastrophic accident would never occur. TMI has demonstrated that scientists and engineers cannot ensure this promised degree of safety. When all is said and done, however, the case can still be made that nuclear power represents the optimum presently available technology for generating electricity, given the realities of the world energy situation; the risks involved, including the credible risks of nuclear accidents, are quite acceptable when compared with the risks of alternative courses of action for meeting our energy needs. But this case can be made credibly only if assurances about the extremely low probability of an accident are linked—in a spirit of full and candid disclosure—to the recognition that such an improbable accident can have enormously catastrophic consequences.

Three Mile Island has made it clear that preparedness for a serious nuclear power plant accident is critical to ensuring that operations of nuclear power plants will not endanger the health and safety of the public; it has also become clear that preparedness is essential for the acceptability of nuclear power. At the same time, meaningful levels of preparedness may paradoxically heighten the impression that nuclear power is too dangerous to be acceptable. An escape from this paradox lies in the old legal tactic of "confession and avoidance." My own conviction is that relentless truth-telling about the risks of nuclear power is the only way to put these risks in true perspective, so as to defuse the present nuclear power controversy. Once this is done, preparedness for nuclear power accidents can be discussed, undertaken, and implemented without exacerbating prevailing antinuclear attitudes.

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THE DETERMINANTS OF OPERATOR PREPAREDNESS FOR EMERGENCY SITUATIONS IN NUCLEAR POWER PLANTS*

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INTRODUCTION

The events at Three Mile Island (TMI) have called attention to the importance of the human element in the overall safety of large-scale technological facilities such as nuclear power plants. The findings of post-accident investigations in the USA (e.g., The President's Commission 1979, USNRC 1979) have supported the idea that improvements in operator preparedness are required in that country. Although the status of operator preparedness clearly varies form one country to the next (as, indeed, does physical plant) the general post-TMI response of the nuclear energy fraternity has been that this is an opportune time to at least review the situation and to look for areas where improvements might readily be made.

One result of these reviews has been the emergence of a number of informal and formal suggestions for creating conditions conducive to improved operator performance (e.g., Bethe 1979, Holden 1979, Pitzer 1979, The President's Commission 1979, Teller 1979, USNRC 1979, Weinberg 1979). The schemes put forward by these analysts each imply a different mental model of human performance that relates changes in particular human- or job-related variables to corresponding (and positive) changes in operator performance. The topics addressed include the selection of 'better qualified' operators; increasing the operators' motivation (willingness) to perform better (e.g., by enhanced social status through higher pay and uniforms); and improving their ability to respond to emergencies (e.g., by rigorous training

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programs, improved control room design). It has also been suggested that the nuclear industry might adopt, intact, personnel management practices from other industries (e.g., civil aviation) where the job characteristics appear, at least at first glance, to be similar to those required for nuclear operations.

The diversity of these proposals, and their many and sometimes conflicting implicit assumptions, encouraged us to explore the relationships among the many variables that, together, shape the performance of the "typical" operator. In this paper we will propose a schematic "model" of operator performance that considers the underlying determinants of both motivation and ability to perform, with special emphasis on the response to emergencies. As there is a tremendous volume of literature bearing on this problem, we shall only try to summarize the perspectives of various research areas. The intention is to provide a starting point for a qualitative understanding of which variables can be viewed as having a significant influence on operator performance and, therefore, what sort of job changes, or additional research, would seem to be effective.

THE OPERATORS' JOB

The operating crew of a nuclear power plant might typically consist of a shift supervisor, two control room operators, and several auxiliary operators. However, the key members of the team are the shift supervisor, who has the overall operating responsibility, and the control room operators who report to him. For reasons of brevity, in the following discussion we shall often use the term 'the operator' rather loosely to mean the shift supervisor and the control room team that he directs. Because the qualifications and training of operators vary from country to country, and sometimes even from one utility to the next within a country, we shall not attempt to review them here. They are, in any case, not central to the aims of this paper.

Normal Operations

The tasks of the operator are basically determined by the fact that nuclear power plants are used as base-load producers. That is, the plants are operated at a constant power level for extended periods of time; thus the crew may be required to execute load changes only six to twelve times per year—these (typically) divided among five shifts. Additional activities during normal operations consist of taking over the plant from the previous shift—usually through a jointly executed check of plant status—and then, in turn, passing the plant on to the next shift. In short, when things are normal the tasks of the operator tend to be monotonous rather than stimulating and challenging (see Bohr *et al.* 1977, for a detailed discussion).

Off-Normal Situations

The most important task of the operator in the event of an off-normal condition is to prevent it from becoming an emergency potentially damaging to the physical plant and perhaps to public health through the release of radioactive material. In other words, the goal is to return to normal operations, if possible, or, if not, to place the plant in a shut-down condition where decay heat can be removed. In the best of situations automatic safety systems will act to shut down the reactor and initiate removal of decay heat. However, these automatic systems might be inadequate to handle situations not anticipated by their designers. This means that the operating crew must continuously 'track' the situation so that they understand the status of the plant, with the help of instrumentation displays and diagnostic aids, and accurately diagnose the reasons for the off-normal occurrence should manual intervention be required. The typical operating crew encounters an 'off-normal' operating condition only about once a year.

Thus the requirements placed on the operator in an off-normal situation are the opposite of those faced in normal operations: he is expected to make correct inferences and decisions about complex phenomena very rapidly, i.e., under conditions which tend to evoke high levels of experienced stress. Even extensive simulator training may not have directly prepared the operator to handle such situations because the simulator cannot simulate what it has not been programmed for, i.e., situations that the designers have not anticipated. (For example, prior to TMI the Babcock and Wilcox simulator "was not.... programmed to reproduce the conditions that confronted the operators during the (TMI) accident" (The President's Commission 1979)). Another difference between simulator experience and actual off-normal events is that the operator may not experience the same level of stress during simulator practice. Thus his performance when handling a real emergency may be reduced, even though he has seen the same situation in simulator training. (The causes of stress and its effects on performance will be discussed below in more depth.)

In summary, there is a dramatic contrast between the demands placed upon the operator in normal operations compared to off-normal situations or emergency conditions.

A "MODEL" OF OPERATOR PERFORMANCE

Figure 1 illustrates how various characteristics of the job, the individual, and the work and social environment come together to shape performance. Performance, as expressed by overt behavior, is represented by the box on the extreme right-hand side of the figure; a large number of behaviors is portrayed because "performance" can seldom be easily defined in the real world. For an assembly line task it might be roughly measured in terms of units produced per hour, but, in reality, job performance consists of a complex package of separate (specific) behaviors. The immediate determinants of these specific behaviors are seen

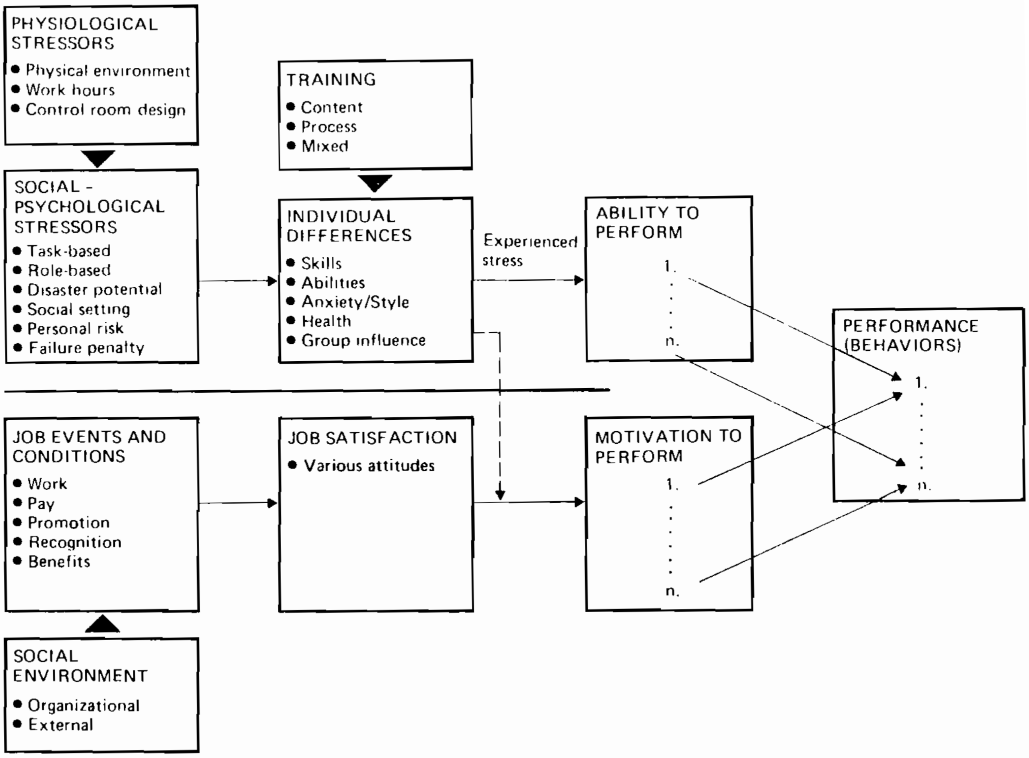

Figure 1. Scheme showing determinants of operator performance.

to be both the individual's motivation (behavioral intentions) and ability (perhaps reduced or enhanced by the stress he is experiencing). The determinants of motivation and ability to perform will be discussed separately.

Motivation to Perform

Our analysis of willingness-to-perform resembles the conceptual framework for attitude studies used by Fishbein and his colleagues to summarize the relations among beliefs, attitudes, intentions, and behaviors (see, for example, Fishbein and Ajzen 1975, Otway and Fishbein 1976, 1977). With respect to our specific interests here, the analogous variables are, respectively, the perceived characteristics of job and social environment, job satisfaction (an attitude)*, and the individual's

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*This is a simplified presentation for purposes of discussion. Actually there are a number of attitudes relevant to 'job satisfaction', e.g., attitude toward the work, toward one's own performance, toward the supervisor, co-workers, etc. (see for example, Hackman and Oldham 1976). The relevant attitude depends upon which behavior is of interest.

motivation (intention) to do the job as it is defined by some set of specific behaviors. These variables are shown in the boxes in the lower half of Figure 1.

The perceived characteristics of the job coupled with the perceived organizational and external social environments are the immediate underlying determinants of job satisfaction. In Figure 1, the line going from the "job satisfaction" box to the edge of the 'motivation to perform' box is meant to show that, once job attitudes have been formed, the individual is predisposed to perform some pattern of job-related behaviors, which, taken together, are consistent with his attitudes. But he is not necessarily disposed to engage in any one specific behavior, i.e., "satisfaction" cannot be inferred from the observation of one specific behavior.

The dashed line originating from the 'individual differences' box in Figure 1 illustrates that people express their attitudes in different ways. For example, two workers could express the same favorable attitude toward their jobs in quite different ways: one by regular and prompt attendance coupled with low job output, the other by an erratic attendance pattern coupled with high productivity when on the job.

The 'building blocks' of the individual's willingness to perform his job, i.e., the perceived characteristics of the job and its social environment, will be discussed next.

Perceived Job Characteristics

What matters most is how the operator perceives his job, not the 'objective' reality. We can expect that job perceptions are largely based upon reality, but that these realities may appear somewhat different to different people—management and labor, for instance. Thus it is not possible to say precisely which job characteristics will, in fact, be related to job satisfaction, but we can look at the sorts of attributes that empirical research has found people typically use to describe their jobs—keeping in mind that there could be an essentially infinite list and that the relevant characteristics will vary from job to job and person to person. They are what the worker believes to be the characteristics of his job.

The usual empirical approach to identify job dimensions is to ask employees to respond to a questionnaire containing a number of job-related items; factor analysis is then used to group the items which correlate highest with each other (a "factor"). The basic job characteristics are then inferred from the content of the items loading on each factor. Of course, each study is likely to find a different factor structure, depending upon the nature of the respondent group, the items scaled, and the interpretation of the factor analysis. However, in general, job dimensions tend to fall into two broad categories: characteristics of job events and conditions (Locke 1976); and the social environment in which the work is performed, both within the organization and outside.

Typical of items in the first category are characteristics of the work itself (autonomy, variety, significance, feedback, etc.; see Hackman and Oldham 1976), pay (amount, fairness, method of payment, etc.), promotion (opportunity, fairness, bases, etc.), benefits (medical, pension, vacation, etc.), and working conditions (hours, rest breaks, physical environment, etc.). The category of social environment would typically include items related to the people within the organization (e.g., co-workers, supervisors, management) who determine the nature of job events and conditions. The social environment outside the organization can also influence a person's feelings about his job; this includes normative influences due to his awareness of how others important to him (e.g., family, friends, community) feel about his job. (Along these lines, one can imagine that the public controversy surrounding nuclear energy may well have had effects upon operators' attitudes toward their jobs.)

With respect to the nuclear power plant operator, job satisfaction and motivation are not likely to be as important to performance as are his skills and abilities. The main reason is that his job is not one of production where, for example, his own desires can largely determine how fast he will work. The particular aspect of performance that is of most interest is his response to infrequent, off-normal situations. It seems rather unlikely that an operator will lack motivation to respond when the alarms go off. The real question when this happens is if the right person holds the job and is able to supply the correct response.

The primary relevance of the "willingness-to-perform" variables to nuclear operations may be in the longer term. For example, because of boredom an operator may gradually lose interest in his job. As he begins to place the job lower in his priorities, it is possible that his ability to respond to emergencies will be subtly reduced, possibly in ways not readily noticeable to his co-workers or supervisors. The US Air Force has sponsored research (see Mudrick *et al.* 1978) to identify 'indicator behaviors' to help diagnose longer-term loss of motivation in fighter pilots; e.g., does he spend his off-duty hours reading material related to his job, does he take advantage of opportunities to 'pick the brains' of more experienced pilots? Loss of motivation can also be shown by leaving the job. High turnover of people with extensive training is expensive and likely to be detrimental to safety.

Pay and Performance

A few words should be said about the effects of pay on job satisfaction and performance. One of the 'intuitively obvious' ways that has been suggested to improve operator performance is to increase pay. Implicit in this idea is the assumption of a direct and positive relationship between pay and performance —which is not supported by the literature.

For example, Deci (1975) found that people involved in a task with high intrinsic interest displayed a decrease in motivation when external financial rewards were offered. In a military setting Frey *et al.* (1974, 1974a) found that performance did not necessarily increase with increased financial incentives and, in fact, it sometimes got worse. Hulin (1969) found that workers from communities with better economic conditions, standards of living, and so forth were less satisfied with their financial rewards than were less well-off workers. He suggested that higher rewards raise the frame of reference used to evaluate incomes, thus leading to a devaluation in the level of pay actually being received. Laboratory research (Pritchard *et al.* 1972) suggests that people who are overpaid are equally, but not more, satisfied with their pay than are those who are equitably paid.

Equity theory (see Lawler 1971) posits that pay satisfaction is a function of pay received in relation to an individual's perception of his contributions as compared to those of others holding similar jobs. Equity theory predicts that overpayment will lead to as much dissatisfaction as underpayment.

These studies suggest that large increases in operator pay would not necessarily make operators more satisfied with their jobs. In view of the uncertain relations between satisfaction and specific items of performance (especially in emergencies), it seems even less likely that an increase in nuclear safety would result. There might even be negative effects, if high pay kept operators in jobs that no longer interested them. It has sometimes been suggested that higher pay would allow operators to be selected from a larger pool of applicants, thus making it possible to hire more intelligent operators with better educational backgrounds. However, it must be remembered that an operator spends more than 99.9% of his time in rather routine operations, and the ability of people selected must correspond to the total job, not just the requirements of infrequent episodes. The reasons for this will be discussed under the topics of stress and selection.

Ability to Perform

In this section, we will explore the factors which shape the operator's ability to perform under the stress of emergencies. We will begin by explaining what is meant by 'stress' and discussing its effects upon performance.

Stress and Performance

Stress is a rather imprecisely defined term. McGrath (1976) has suggested the following working definition: "there is a potential for stress when an environmental situation is perceived as presenting a demand which threatens to exceed the person's capabilities and resources for meeting it, under conditions where he expects a substantial differential in the rewards and costs from meeting the demand versus not meeting it." Stress results then from an interaction between the person and his environment.

In lay terminology we could say that stress is simply mental or physical tension resulting from any external or internal source (event, condition, etc.).

It is important to note that it is the subjective experience of stress that affects performance, i.e., the person's perception (cognitive appraisal) of the 'objective' stress-inducing situation. Some typical causes of stress will be discussed below.

The generally accepted relationship between experienced stress and performance is shown in Figure 2. This inverted-U relationship suggests that performance is poor at very low stress levels (for an explanation see Scott 1966), increasing as stress rises to an 'alertive' level. However, as experienced stress continues to increase, 'disruptive' levels are reached and performance begins to deteriorate.*

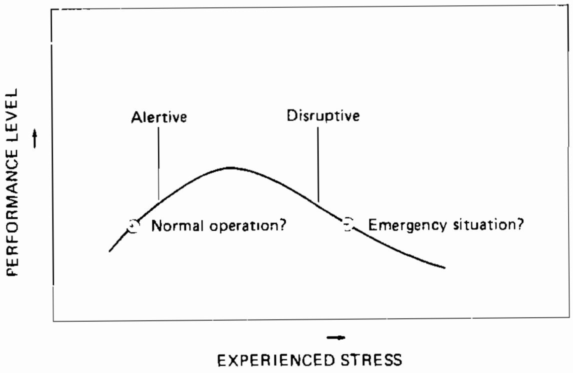

Figure 2. Plot of hypothetical stress-performance relationship.

One goal of job design is to achieve a level of arousal that allows near optimal performance. This, in turn, requires an understanding of the typical causes of stress. First, some rather general statements can be made about stress and performance. For example, it has been found that past experience with a stressful situation or stressor condition, as well as practice or training, can act to influence the level of stress experienced. There is also a reinforcement effect, for past successes or failures in these experiences also have a bearing on stress. Finally, interpersonal relations, due to the presence (and activities) or absence of others can influence experienced stress and performance

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*For example, Appley and Trumbull (1967) estimated that the error rate for very low stress, passive inspection tasks may be as high as 0.5. Studies of military personnel exposed to extremely stressful conditions (flight crew response to in-flight emergencies, behavior under realistically simulated combat conditions) have recorded error rates in the range of 0.16 to 0.33 (Ronan 1953, Berkun 1964).

by increasing arousal, causing irritation or antagonism, providing sources of self-esteem and affiliative feelings, and so forth. Zajonc (1965) has suggested that the presence of others leads to increased arousal and thus to an increased probability of selecting the dominant (i.e., 'best-learned') response, with a corresponding decrease in the probability of a 'new' response should the best-learned response be inappropriate. This finding may be relevant to operator actions in the early stages of the TMI accident.

In the following sections, specific determinants of stress will be discussed in more detail. Note that stress is treated as a social-psychological state that can be affected by the physical environment in which the job is performed.

Physiological Stressors

Returning to Figure 1, a group of physiological stressors is shown above the box labeled "social-psychological stressors." These physiological stressors can include aspects of the working environment such as temperature extremes, lighting, noise*, fatigue brought on by long working hours, shift work, or insufficient rest periods. The variable in this category most likely to affect the stress experienced by the nuclear power plant operator is the design of the control room itself (as was seen in the case of the TMI accident). It has been observed (e.g., Weinberg 1979) that nuclear power plants in the USA were treated by utilities as just another type of generating station. Consequently, the state-of-the-art of human-factors engineering (developed, for example, in aerospace programs) was not reflected in nuclear plant control room design (see also Skans *et al.* 1974, Bohr *et al.* 1977). This is an area in which the work undertaken in research centers like Halden and Risø can make an important contribution to easing the demands placed on operators confronted with emergency situations.

Social-Psychological Stressors

The most obvious sources of stress in the category of social-psychological stressors are the perceived characteristics of the task itself. For example, tasks which must be performed at high speed and load tend to increase stress. But it should be noted that exact opposites can be sources of stress, e.g., overload and underload, monotony as well as time pressures (see Marshall and Cooper 1979).

Stress is also increased in the following situations: when the individual believes that the consequences of poor performance

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*Although the physical working conditions in a nuclear plant are certainly adequate, a paradox of the TMI accident was that the distraction caused by excessive emergency alarms seems to have been a stress factor (The President's Commission 1979).

could be disastrous (the case of nuclear operators and airline pilots); if the individual himself is also personally at risk (clearly so for the airline pilot, not likely for the nuclear operator); and if poor performance will be penalized (retraining assignment, demotion, loss of job, financial or criminal liability). In addition, stress may originate from role-based factors, i.e., ambiguity and confusion about exactly which operational role the individual is expected to fill. Stress may also be affected by the behavioral setting, through undermanning or overcrowding; further sources of stress might be found in the social environment—reflected by interpersonal disagreements caused, perhaps, by isolation or lack of privacy.

The primary relevance of this category of stressors to nuclear operations is that job designers should try to ensure that normal operations are not excessively boring or monotonous. This means that the job design should strive for an alertive level of stress in order to prevent errors by understressed operators that could cause off-normal events. More importantly, job designers should not allow stress in off-normal situations to reach dangerous levels by expecting the operator to handle a large number of tasks under the pressure of time. This will be discussed in more detail below.

Individual Differences

Of course each individual will respond differently to stressful conditions—hence the box marked "individual differences" in Figure 1. For purposes of discussion, we may think of each individual as being characterized by the abilities and skills that he brings to the job. We will treat abilities as being rather basic and fixed aspects of the individual, e.g., intelligence and visual acuity, although, in fact, these can be changed somewhat by education, training, and practice. Skills, in contrast, are more task-specific and may be conceptualized in terms of three broad classes (Hinrichs 1976): motor skills (manipulation of the physical environment); cognitive skills (ways of thought and systems of belief); and interpersonal skills (self-awareness and effective functioning in social interactions). In addition, individuals differ in terms of personality*, physical and mental health, their susceptibility to group influences—all of which will affect the level of stress experienced. There is also a certain amount of stress that the individual brings to the job in terms of his own anxieties and perceptual styles.

The intent of training is skill enhancement. Because of its importance to nuclear operations, training will be saved for a later discussion. The other variables in the "individual

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*Personality will not be discussed further in view of the findings (Mischel 1973, Sarason *et al.* 1975) that personalities do not seem to be deep-seated, permanent variables, and in any case are relatively insignificant compared to situational variables.

differences" category, being more enduring in nature, are best treated under the heading of personnel selection.

Selection

Selection is an attempt to match the needs of people and organizations. The basic idea is to determine characteristics of people that will relate to subsequent performance on the job. This is a big order on two counts: first, people can differ from each other in so many ways (on more than one million measurable and relatively independent dimensions (Rigby 1970)), and second, it is difficult to describe job performance in terms of the particular package of human characteristics that such performance requires.

In his review of the personnel selection literature, Guion (1976) noted that the principles and practices of selection published by Freyd in 1923 are still relevant today; Guion showed that relatively few employee selection procedures have been validated by demonstrations that they describe the skills and knowledge necessary for successful on-the-job performance. An example may be seen in the discrepancy between typical testing procedures for secretarial applicants (15-minute typing test, dictation test) and the requirements for the effective performance of the actual job, which may require skills in organization, travel planning, drafting correspondence, etc. Ghiselli (1966) has suggested that it is easier to predict trainability for a job than to predict job performance itself.

Thus it is doubtful that complicated selection tests can uniquely identify the best candidates for the position of nuclear power plant operator. Formal selection procedures are perhaps best for rough screening, to eliminate those who are uneducable, intellectually unsuitable, or excessively responsive to stressful situations. It is important to observe that it is just as necessary to screen out candidates who are overqualified for the job because they may be insufficiently challenged and thus perform poorly. This is of special relevance to the selection of nuclear power plant operators where there is a marked contrast between the requirements of normal versus emergency conditions. A highly intelligent, well-educated operator stressed by the boredom of normal operations might even become the cause of an emergency.

Training

Training is any organizationally-initiated procedure designed for the education of employees or the acquisition or enhancement of skills—cognitive, motor, or interpersonal. Despite the volume of training activity in public and private sectors, Hinrichs' 1976 review of the personnel training literature concluded that "little psychological knowledge about the field has been developed." By this he meant that the field has been dominated by practitioners who have either assembled a "training program" as an end in itself without first establishing what its goals should be, or that the things that seem to work have been determined through iteration (as reflected by 'acceptable' performance) without finding out why. This makes it difficult to generalize experience gained in, say, pilot training to another area such as the training of nuclear plant operators.

In Figure 1 training is shown to provide an input, i.e, skill enhancement, to the "individual differences" box. Training efforts can be thought of as falling into three broad categories (Hinrichs 1976): content techniques designed to impart knowledge or information; process techniques concerned with the development of interpersonal skills, self-awareness, etc.; and mixed techniques used to impart substantive knowledge for activities where group processes are also important.

Content-oriented approaches include lectures, the use of audio-visual devices such as films and slides, and techniques for self-instruction, e.g., programmed instruction (PI) and computer-assisted instruction (CAI). Content techniques alone are clearly not adequate for the training of nuclear operators, but can be a useful tool for teaching conceptual principles and providing technical knowledge prior to skills training. The lecture technique, despite its widespread use in formal education programs, has been quite generally criticized (Korman 1971). The 'teaching machine' approach (PI and CAI) is promising, and is being increasingly used, although there is evidence (Goldstein 1978) that it is not always superior to traditional methods of instruction. The success of these new methods is completely dependent upon the careful design of the instructional program. These methods can be relatively expensive compared to conventional instruction.

Process-oriented techniques are of less relevance to the training of nuclear plant personnel. The following are examples of these techniques: role-playing, to increase sensitivity to the position of others in the organization, thus bringing about change in attitudes; sensitivity training, which deals with the feelings and perceptions of the group members and the behavioral processes operating in the group; and the modeling of behaviors to be learned by demonstrating the desired behaviors (e.g., by using filmed examples) and then reinforcing these behaviors in role-play practice.

Of most interest for the training of nuclear power plant operators are the mixed techniques that endeavor to impart knowledge as well as to enhance the skills needed by trainees to function as members of a team. The methods used include conference discussion and case study analysis, which are superior to lectures because they involve the participants to a greater extent and provide feedback; on-the-job training programs; and, perhaps most attractive for nuclear operator training, the use of simulators. Simulators have gained widespread acceptance in areas where the acquisition of motor skills is important, such as military and aerospace programs, and have assumed particular importance in the training and requalification of commercial air transport pilots.

Simulators have the great advantage of not penalizing poor performance. That is, there is no loss of life if faulty performance in an airplane simulator leads to a "crash." Further, simulators can be used to practice emergency situations that could hardly be duplicated at will in the real system, e.g., an airplane engine fire. Also, the cost of simulator training may be only a fraction of the operating cost of the real system.

Simulators also have disadvantages. One of the more obvious is that they can only be programmed to simulate conditions that have been anticipated by their designers and deemed 'credible' enough to be included in the simulator repertoire. Another drawback is that trainees may tend to focus on the responses they have learned to cope with simulator behavior, thus lessening their ability to improvise should an unanticipated situation arise. Finally, there is the question of realism. In the end, the trainee knows that he is in a simulator and thus may experience considerably less stress than he would in operating the real system; thus simulator performance (training validity) might be significantly better than that in the real situation (performance validity).

Intuitively, simulators often seem to be an obvious solution to the training problem. However, and perhaps because of this, there is little information available on just how effective they are as a training tool. Hinrichs (1976) wrote that "...there is a surprising absence of conclusively controlled research to test their effectiveness or to identify general principles for their design." In fact, this statement is equally true of virtually all training methods, including on-the-job training.

Goldstein (1978) proposed four stages to establish the validity of a training program. The first is training validity, which refers to the ability to master the instructional program itself. The second is performance validity, an indication of skill transfer from the training environment to the actual job setting. The third and fourth stages, intra- and inter-organizational validity, concern, respectively, generalization to other groups of trainees within the organization, and generalization to trainees in other organizations. Performance is obviously affected by a larger number of variables at each successive stage. For example, although the required motor and cognitive skills may have been mastered in training, organizational constraints may interfere with their performance in the work environment. Most training programs, if they are evaluated at all, are concerned primarily with establishing training validity, which itself is not a trivial task.

In the case of the nuclear power plant operator, we are primarily concerned with performance validity. This requires, first of all, a careful assessment of the needs of on-the-job performance, including consideration of organizational goals, resources, and constraints. It is tempting to accept the high-fidelity simulator as a valuable and necessary part of operator training—and, indeed, it may be valuable. But, remembering the warning about the dangers of developing a training program to fit the training devices at hand (Gilbert 1960), we would be well advised to 'start from scratch', keeping an open mind with respect to reactor simulators, and to base the mix of training techniques on a sound assessment of performance needs and objectives.

DISCUSSION

A large number of factors can, in principle, be instrumental in shaping performance, although their relative importance varies from situation to situation. In the particular case of the nuclear operator we have tried to show that some of the 'intuitively obvious' ways to improve performance by the manipulation of specific factors might not produce the expected results. For example, selecting operators with especially high intelligence (and there is some question about exactly what it is that IQ tests measure) would not necessarily result in improved emergency response and, in fact, might even lead to a performance decrement in view of the long, relatively monotonous, periods of normal operations. Likewise, there is no evidence that large pay rises would result in better performance or, indeed, even more job satisfaction. Again, the effect could even be negative. Even the notion that true-to-life simulators are the best way to train operators is a largely unproven assumption—although the contrary has also not been established.

Another idea that does not bear closer scrutiny is that personnel management practices (e.g., selection procedures, compensation levels, training programs) from some other, apparently similar area of activity could be adopted as a package for use in nuclear operations—the job of the commercial airline pilot often being suggested as an analogy. The validity of this analogy can be explored in light of the model presented earlier.

To begin with, the jobs themselves are very different. Even in normal flight conditions the cockpit crew must respond to a continuing series of routine demands, e.g., resetting navigational aids, position cross-checking, radio communications, which (under Visual Flight Rules (VFR), with autopilot) are superimposed upon a job somewhat similar to the nuclear operator's. Under Instrument Flight Rules at least one of the pilots is required to perform a rather typical vigilance task involving rapid cross-checking of basic flight instruments. In addition, the pilot's physical well-being (in contrast to that of the nuclear operator) is intimately linked to the safe operation of the aircraft. Thus, during normal operations, the pilot would be expected to experience a level of arousal closer to the optimum of the stress-performance curve (Figure 2). The typical airline cockpit crew also encounters 'off-normal' conditions more frequently than the nuclear plant operator*. Having had

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*'Hard' numbers are not readily available but one of the author's (HJO) experience as a professional pilot suggests that some tens of unexpected (i.e., off-normal but not necessarily emergency) occurrences requiring action might be experienced each year.

the positive reinforcement of satisfactorily coping with these situations (as well as the stress of frequent recertification tests in simulators), the pilot should experience less stress in an emergency.

The jobs are also quite different in terms of motivating factors. The intrinsic interest of the pilot's job is certainly greater, especially when we remember that man has always been fascinated by flight, a recurring mythological theme. We could stretch the point a bit and say that the pilot's job was desired even before the airplane existed—the same could hardly be said of the nuclear plant operator. Another difference is that the pilot provides an obvious social benefit—it is clear to the passengers, for example, that they have been rapidly transported from one place to another and who has piloted the plane. The pilot also enjoys virtually complete autonomy when airborne, and gets positive performance feedback from each flight.

One of the justifications given for proposing increases in operators' pay is that it should be commensurate with their responsibilities as measured by potential public hazard; often pilots' pay and responsibility have been offered as a model. However, pay is seldom related to only one variable—such as potential for loss of public life. For example, using this criterion, it is not obvious that the responsibility of the pilot is greater than that of the air traffic controller, although the pilot's pay is several times greater. Pay scales may be more influenced by the nature of collective bargaining arrangements than by the objective characteristics of the jobs themselves*; pilots have had a very effective bargaining position in comparison to the air traffic controllers who, in most countries, are civil servants.

There are very few civilian jobs closely resembling that of the nuclear power plant operator; the most similar is perhaps the operation of chemical process plants. But indications are that little attention has been given to preparing chemical plant operators to handle emergencies (Albracht 1979). The practices of other industries are best viewed as sources of ideas that may, or may not, be relevant to the case of nuclear operations.

CONCLUSION

The intention of this paper was to approach the question of operator preparedness for emergencies from the scientific perspective provided by research on human performance. Our findings can be grouped under three headings: the identification of existing practices that have a sound scientific basis (although unsound proposals to change some of these practices have been made since the TMI accident); a discussion of some aspects that

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*An additional factor is that, in VFR weather, the air crew could in principle transport passengers without air traffic control personnel. The reverse is never true.

might be considered in redesigning the operator's job; and mention of research needs related to operator performance.

Present Practice

In view of the high level of stress an operator is likely to experience in an off-normal or emergency situation, it is especially important that he should not be expected to take decisions in the early stages of a crisis. The worst time to think is when under pressure. For example, Swain (1975) estimated that operator error rates following a large loss-of-coolant accident would decrease to steady-state levels (the specific numerical level depending upon the situation) only after 25-30 minutes. Siegel and Wolf (1969) theorized that, under severe time stress, the normal error rate for a corrective action would double if the previous corrective attempt was erroneous or ineffective. If the initial error rate is relatively high, say 0.2, it takes only a few attempts to reach a rate of 1.0, corresponding to complete disorganization (Appley and Trumbull 1967). The symptoms of all emergencies that can be anticipated must be related to emergency checklists so that no actions, however elementary, have to be improvised by decision of the operator. (This is also standard airline practice.) The question of unanticipated situations will be discussed below.

Although detailed practices differ among countries, the policy generally is both to design safety system response so that no operator actions are (typically) required in the first 30 minutes of an anticipated emergency, and to provide detailed contingency checklists. These policies have a sound scientific basis.

Because of the difficulties involved in relating subsequent on-the-job performance to formal preemployment testing, existing selection procedures must not necessarily be changed if they seem to be working satisfactorily. Formal testing is best suited to screen out those candidates who are clearly underqualified or overqualified.

There seems to be no obvious reason to contemplate drastic increases in operator pay. The key word here is 'equity': operators must receive compensation that is 'fair', in terms of their qualifications, the demands placed upon them, and the salaries available for similar jobs elsewhere. However, in view of the public opposition to nuclear energy, it might sometimes be necessary to pay a premium if the job is perceived by the community to be of low status.

Considerations for Job Redesign

A paradoxical situation exists between the demands placed on the operator in normal and emergency conditions. During periods of routine operation he may be experiencing so little stress that his performance is suboptimal (see Figure 2); then, when an emergency arises, arousal may rapidly increase to such a high level that performance remains suboptimal. This paradox could be resolved by changing the job so as to increase arousal during normal operations and to decrease the stress experienced in emergencies. Aside from changes in the physical environment (e.g., improved design of control panels and alarms), we can speculate as to how the job or its organizational aspects might be modified to help achieve stress levels nearer the performance optimum in both conditions. Approaches that have been successfully used in military settings to address this problem include the ideas of 'non-lethal defects' and 'realistic drills' (Hulin and Triandis 1981). In order to stimulate discussion we will explore below how such concepts might be used in the context of nuclear operations.

The reason for suboptimal stress levels during normal operations is simply that not much is happening and, indeed, the operator is not expecting much to happen—i.e., he holds a low subjective probability for the occurrence of an off-normal situation. 'Non-lethal defects' means the intentional creation of nonhazardous system irregularities that must be discovered and corrected by members of the operating team. For example, a valve that should be found in the closed position on a checklist might be intentionally (and surreptitiously) opened by management prior to checklist execution (if this poses no hazard to people or equipment). These apparent defects must occur often enough (say several times per week) that operators expect to find unusual conditions, even during routine operations, thus increasing arousal. Needless to say, for such an exercise to have meaning there must be a direct relationship between performance of these tasks and job evaluation for promotions, pay rises, etc.

'Realistic drills' extend this principle to the high-stress side of the performance curve. The nuclear power plant equivalent of military practice could involve a second control room; unbeknown to the operating team, actual control would be switched to the second control room (manned, for example, by qualified management personnel), while the operator's controls would be switched to a simulator. Emergencies would be simulated at least once a week in this way without the operating crew knowing for sure if it is a simulation or a real emergency.* Again it is essential that performance on these drills be treated as if the drills were 'real' in evaluating operating crews for promotion, etc.; in addition there must be the possibility of penalties, e.g., dismissal, for poor performance.

If performance on drills is rigorously evaluated, they become stressful events—even though the operators know they are most likely simulated—and thus allow the operators to acquire an increased tolerance for stress. (As mentioned earlier, experience, practice, and positive reinforcement have been found to lower experienced stress, resulting in better performance in real emergencies.)

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*A military equivalent, drills of a missile-firing crew, could go as far as the actual firing of a (secretly) redirected and disarmed missile.

Some qualifications must be made here. It is not seriously proposed that plants should be built with duplicate control rooms (or that they should not), or that the ideas presented above would necessarily be successful in the nuclear field. We want to suggest only that schemes successfully used in military, aviation, and other contexts to enhance performance should be examined to detect principles that hold promise for helping to resolve the normal vs emergency paradox of nuclear operations.

To some extent the notions of 'realistic drills' and 'nonlethal' defects just provide operational details for the 'nuclear priesthood' (Weinberg 1972), an elite, highly disciplined cadre of nuclear experts. But we should remember that these organizational 'fixes' are basically of military origin and, indeed, it might be difficult to enforce penalties for poor performance in a nonauthoritarian atmosphere. There is an implication here that nuclear operations might have to assume a quasi-military character, something that some nuclear critics (e.g., Jungk 1978) have cited in opposition, asserting that the social institutions required by the technology are inconsistent with the ideals and traditions of democratic societies. This raises the possibility of another potential paradox: that organizational measures taken to reduce risk (in the physical sense) could enhance perceptions of social risk and thus have the net effect of increasing public opposition (Otway *et al.* 1978).

A problem that might be encountered in making performance on drills a strong determinant of the operator's career prospects is that it obviously requires the existence of a career structure. This, of course, implies a growing nuclear program; but, because of public opposition, this is not the case in many countries. Thus fundamental organizational changes might be necessary to provide sufficiently attractive career advancement possibilities, e.g., by combining the operational side of all energy sources on a national basis—although this might be inconsistent with maintaining a high level of expertise in the nuclear field.

Research Needs

Our review suggests that there are several areas where additional information could improve our understanding of operator performance and its role in nuclear safety. Some work must be done to improve the design of nuclear control rooms, (e.g., in terms of optimizing the layout of control panels, the amount and type of information available, the provision of diagnostic aids, and the optimization of alarm hierarchies). Analyses should be performed to determine the needs and objectives of nuclear operator training prior to the design of new training initiatives, and attention should be given to the evaluation of these programs. It is easy to say that training should be improved, but it is quite another thing to show which particular combination of, for example, classroom instruction and simulator training are optimal, and at what level of simulator fidelity. It would be useful to investigate the stress levels experienced by operators in normal operations and simulated emergencies and to learn more about the sources of these stresses. Implicit in all of the foregoing is a theoretical task analysis to better define what is expected of each operating team member in various emergencies.

Finally, thought should be given to ways in which the operator's job itself, and the organizational environment in which it is performed, might be modified to enhance the overall safety of nuclear operations. But careful, scientific analyses are required; many of the intuitively appealing suggestions made in the aftermath of the TMI accident, upon closer examination, may be ineffective or even deleterious. This cautionary note can be taken in a more general way to apply to all changes initiated in response to TMI. It is entirely possible that a modification, too narrowly specific to TMI, or poorly conceived or executed, could become the cause of the next accident.

A principle of current plant design is that control and safety systems are designed to respond automatically to all of the significant accident sequences that can be anticipated. These automatic responses will have been carefully thought out and discussed by the designers without the pressure of time. Should one of the anticipated accident sequences actually occur there should not be much need for the operator, or at least no creative role for him. The paradoxical implication of this is that the operator is most needed when a completely unanticipated situation arises—when he must rapidly diagnose and respond to a situation not included in his training. However, the research we have reviewed suggests that these are precisely the conditions to which he would be least able to respond in a constructively creative way.

Here we should explore the implications of the argument that the operator is not really required for anticipated events and that he might be of little use for unanticipated events. This requires us to evaluate a trade-off between two possibilities: that an unnecessary operator action, made under stress, aggravates otherwise 'routine' recovery from an anticipated event that could have been handled by automatic systems (apparently the case at TMI); and that a correct diagnosis and intervention (under extremely stressful conditions) would actually effect recovery from an unanticipated accident sequence. It is possible that the human element will remain the weak point in the overall safety of nuclear power plants. In any speculation about the redesign of the operator's job, thought should at least be given to the possibility of its elimination, or at least to its redefinition as a more routine monitoring task with extremely limited possibility for intervention in emergencies.

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18

LIABILITY FOR NUCLEAR ACCIDENTS: IMPLICATIONS FOR POST-ACCIDENT RECOVERY

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INTRODUCTION

The ability to provide adequate compensation for financial losses resulting from a nuclear accident may be one of the primary factors in determining the recovery rate of the affected community. Some costs, such as the expense of evacuating nearby residents, must be met while the crisis is still in progress. Others, such as the costs of restoring facilities and purchasing replacement power during the interim period, may be of concern for months or even years after the crisis has subsided.

This paper examines the various types of liability for damages resulting from an accident at a nuclear power facility and the mechanisms for compensating these losses in the post-accident recovery phase. Attention is first given to the Price-Anderson Act, which has been a source of controversy because of the limits it places on liability for nuclear accidents in the United States. The insurance industry is then considered in terms of its role under the Price-Anderson Act. Finally the successes and failures of the existing compensatory systems are considered in terms of their effect on post-accident recovery and on the future of nuclear power in general. Examples from the accident at Three Mile Island will be used wherever possible to illustrate the different categories of losses and compensatory mechanisms.

THE PRICE-ANDERSON ACT

Background

With the enactment of the Atomic Energy Act of 1954, private industry was given the opportunity to participate in the peaceful

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applications of nuclear energy. Although private industrial and business interests appeared eager to invest in the then infant industry, it soon became obvious that the potential liability for a nuclear accident might prove to be an insurmountable barrier to the development of commercial nuclear power.

Recognizing that special measures might be required, the Atomic Energy Commission created a study group of insurance industry representatives to study the insurance problems associated with the peaceful applications of nuclear energy (Lowenstein 1977, p. 597). In its preliminary report to the Commission in June 1955, the group concluded that the primary difficulties would involve liability to third parties (the general public in this instance). The group found that there would be little difficulty in providing property (first party) coverage for nuclear facilities and concluded that employees (second parties) injured in an accident would be covered under workmen's compensation programs in existing insurance plans.

A basic problem for the insurance industry was the question of how to calculate the probability of an accident. The limited number of nuclear plants operating in the 1950s provided few data for developing an actuarial base to calculate insurance premiums on the basis of risk. Thus while the industry was eager to participate in a potentially lucrative venture, it was operating without the most fundamental tools of the insurance profession. As one commentator (Marrone 1977, p. 609) stated:

> In 1957 the underwriters were frank to say that they did not know what the proper premium charge would be for nuclear insurance. As a result of this, a unique industry-wide credit rating plan was developed. The premium to be charged for each risk would be affected by the loss experience of the entire nuclear industry.

The private insurance industry eventually agreed to provide liability coverage ranging from 50 million to 60 million dollars, a sum which was four times greater than any public liability policy previously available to any single US industrial plant (Green 1973, p. 484). Yet the atomic energy industry regarded even this unprecedented amount of coverage to be inadequate and the insurance problem continued to roadblock the private development of nuclear technology (Green 1973, p. 484).

Congress considered the nuclear liability question through a series of extensive studies and congressional hearings in 1956 and 1957. In 1957, an indemnity statute was enacted as an amendment to the Atomic Energy Act of 1954. This amendment is generally referred to as the Price-Anderson Act (Price-Anderson Act of September 2, 1957).

Purposes and Scope of the Price-Anderson Act

The two central objectives of the Price-Anderson Act were to insure that the public would be compensated if an accident did occur and to set a limit on the liability of private industry in order to remove the roadblock to large-scale private participation in the development of nuclear energy (Lowenstein 1977, p. 597). The original Act was not intended to establish any new rules of liability. Rather, it was indemnity legislation designed to guarantee the availability of funds to satisfy claims up to the established limits.

The Price-Anderson provisions for limited liability have been criticized by some on the grounds that the public could be deprived of the opportunity to collect for losses in excess of the insurance and indemnity (presently 560 million dollars, as discussed below). However, in a report to Congress, the Joint Committee on Atomic Energy (1965) stated an alternative view:

> It is the committee's view that this limitation does not, as a practical matter, detract from the public protection afforded by this legislation. ...[In] the event of a national disaster of this magnitude, it is obvious that Congress would have to review the problem and take appropriate action. The history of other natural and man-made disasters, such as the Texas City incident, bears this out. The limitation of liability serves primarily as a device for facilitating further congressional review of such a situation, rather than as an ultimate bar to further relief of the public.

Nevertheless, the Act has been the subject of intense controversy because of the claim that its twofold purpose of promotion and protection has evolved to the point where promotion greatly outweighs any public protection afforded by the measure (New England Law Review 1975; Stanford Law Review 1978).

Basic Provisions of the 1957 Act

The 1957 Price-Anderson Act required, as a condition of each operating license and construction permit issued by the Atomic Energy Commission (AEC), that the licensee maintain third party liability insurance up to the maximum amount available from private sources (Green 1973, p. 487; 42 U.S.C. Sec. 2210(b) (1976)). In 1957 the private insurance industry was offering 60 million dollars in liability coverage. Therefore, each licensee was required to maintain at least this amount of financial protection. However, the licensee was not required to maintain this protection in the form of insurance, but could seek "private contractual indemnities, self insurance, other proof of financial responsibility or a combination of such measures." (42 U.S.C. Sec. 2210(b) (1976)).

One of the central provisions of the Act was the requirement that each licensee enter into a 500 million dollar indemnity contract with the AEC (Price-Anderson Act 1957, codified at 42 U.S.C. 2210(c) (1976)). This agreement operated to indemnify any parties which might be in contractual privity* with the utility, i.e., subcontractors, designers, manufacturers, etc. (Green 1973, p. 488; Joint Committee on Atomic Energy 1957). However, the insurance and indemnity coverage also extends to any party, even strangers**, who might be subject to liability as a result of a "nuclear incident," which is defined in 42 U.S.C. Sec. 2014(q) (1976) as "any occurrence...causing...bodily injury, sickness, disease, or death, or loss of or damage to property or loss of use of property, arising out of or resulting from the radioactive, toxic, explosive, or other hazardous properties of source, special nuclear, or by-product material."

The protection offered under the indemnity agreement was intended to ensure that the public would be protected from any nuclear incident regardless of the identity of the causal party. However, in its original form, the Act required that a party be found liable under applicable state law before any claims could be satisfied. This provision prompted considerable discussion among legal scholars over which elements of fault or negligence might be required or whether principles of *res ipsa loquitur**** or absolute liability**** might apply in the case of a nuclear incident (Seavey 1958). Concern was also expressed over the possibility that burdensome requirements of proof might prevent genuine claims from being compensated (New England Law Review 1975; Stanford Law Review 1978). Although this possibility may never be eliminated entirely, the mechanisms for establishing liability have been modified by amendments to the Act. These amendments will be discussed below.

The AEC indemnity of 500 million dollars combined with the 60 million available from private sources gives an aggregate liability coverage of 560 million dollars. If it is apparent that the total damages will exceed this statutory limit, a US District Court with bankruptcy venue† over the location of the accident

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*The concept of privity pertains to the relationship between a party to a suit and a person who was not a party, but whose interest in the action was such that he will be bound by the final action as if he were a party (Black's Law Dictionary).

**Note also that the indemnity applies to "the licensee and other persons indemnified" (42 U.S.C. Sec. 2210(c) (1976)). Furthermore, the "person indemnified" is defined to mean "the person with whom an indemnity agreement is executed, or who is required to maintain financial protection, and any other person who may be liable for public liability" (42 U.S.C. Sec. 2014(t) (1976)).

****Res ipsa loquitur* is a rule of evidence whereby the negligence of the alleged wrongdoer may be inferred from the mere fact that the accident happened, provided that the character of the accident and the circumstances attending it lead reasonably to the belief that in the absence of negligence it would not have occurred (Black's Law Dictionary).

****Absolute liability is responsibility for damages without the showing of fault or negligence.

†Venue deals with the question of whether the court has jurisdiction to hear the suit in question.

is required to serve as a clearinghouse to review claims and apportion the available funds among the various claimants.* Hence the Price-Anderson Act does not guarantee that the public will be fully compensated for all losses resulting from a nuclear incident if the aggregate liability exceeds 560 million dollars. However, a subsection of the Act promises that Congress will "review" the situation and take "appropriate" action if an accident causes damages in excess of the 560 million dollar ceiling (42 U.S.C. Sec. 2210(e) (1976); Joint Committee on Atomic Energy 1965).

The original Price-Anderson Act was regarded as a temporary measure, with indemnity provisions applicable only to licenses issued between August 30, 1954 and August 1, 1967 (Green 1973, p. 491). The termination of the indemnity provisions was based on the hope that the insurance industry would eventually develop an independent program to insure nuclear facilities. As the Joint Committee on Atomic Energy stated: "during the ten year period it is hoped that there will be enough experience gained so that the problems of reactor safety will be to a great extent solved and the insurance people will have had experience on which to base a sound program of their own" (Lowenstein 1977, p. 597; H.R. Rep. 435, 1957, p. 9).

Modifications in Provisions 1957-1975.

In June 1965 the Joint Committee on Atomic Energy began hearings on the possibility of extending the Price-Anderson Act for a second ten-year term to August 1, 1977. During the first eight years there had been a substantial increase in private investment in nuclear power plants and there had been no accidents causing injury to the public. Yet, in the view of the Committee, the "theoretical possibility" of a catastrophic accident and the potential liability remained as great a deterrent to "necessary industrial participation" in nuclear technology as it had been in 1957 (Green 1973, p. 493; H.R. Rep. No. 435, 1957, p. 9).

In September 1965 Congress passed legislation to extend the Act for a second ten-year term (Act of September 29, 1965). Under the terms of the extension, the private insurance industry agreed that it would, from January 1, 1966, increase its liability coverage to 74 million dollars. However, the aggregate coverage under the insurance and indemnity plan was to remain at 560 million dollars. Under an amendment to the Act, the government's indemnity contribution was reduced "by the amount that the financial protection required shall exceed $60,000,000 (42 U.S.C. Sec. 2210(c) (1976)). Thus the net effect was to reduce the amount of government indemnity from 500 million dollars to 486 million dollars, while preserving the aggregate liability ceiling at 560 million dollars.

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*Venue provisions are found in 42 U.S.C. Sec. 2210(n)(1)(1976). The apportionment provision was originally part of 42 U.S.C. Sec. 2210(e), which was deleted and replaced by similar provisions in a 1966 amendment. These provisions may be found in 42 U.S.C. Sec. 2210(o) (1976).

In a modification adopted in 1966, Congress provided simplified measures for handling claims in the event of an emergency (Public Law 89-645). The new provisions allow a claimant to receive immediate partial compensation. However, if the court with venue over the accident determines that total liability might exceed the 560 million dollar limit, emergency payments must be limited to no more than fifteen percent of the total fund. The amendment also contains a provision to reserve a portion of the fund for latent injury claims.

A more fundamental amendment adopted by Congress in 1966 dealt with the issue of establishing liability for damages resulting from a nuclear accident. Under traditional tort law most states required that, in the absence of provisions for liability without fault*, a claimant must establish negligence in order to recover damages. This burden of proof could become a barrier to recovery, since the relevant evidence might be destroyed by the accident or rendered unavailable for a period of time exceeding the statute of limitations. Furthermore, proving actual damages would be especially difficult because it often takes many years for the damaging effects of radiation exposure to become manifest.

Faced with the concern that the protection offered by Price-Anderson might prove to be illusory in light of the substantive and procedural obstacles which could prevent compensation for legitimate claims, Congress was under pressure to enact a federal law to establish strict liability with respect to nuclear incidents. A bill enacted in 1966 established, in effect, the principle of absolute liability for nuclear accidents (Green 1973, p. 496; P.L.89-645). However, rather than explicitly establishing such a rule, the legislation provided for the waiver of certain defenses, thus giving the net effect of absolute liability. Licensees are required to waive "any issue or defense as to the conduct of the claimant or fault of the person indemnified." In addition, there is a provision for the waiver of "any issue or defense based on any statute of limitations if the suit is instituted within three years from the date on which the claimant knew, or reasonably could have known, of his injury and the cause thereof, but in no event more than ten years after the date of the nuclear incident." (42 U.S.C. Sec. 2210(n)(1)(1976)).

In order to prevent nuisance suits and spurious claims, the waivers are restricted by 42 U.S.C. Sec. 2014(j) (1976) to suits involving an "extraordinary nuclear occurrence," an event causing substantial damage to persons or property as a result of the release of radioactive materials from a nuclear facility. Final authority for determining extraordinary nuclear occurrences belonged to the AEC** (this power is now vested in the Nuclear

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*The principle of liability without fault and its variants relies on the rule established in *Rylands* v. *Fletcher*, 3 H.L. 330 (1868). See Seavey (1958), p. 7.

**The Atomic Energy Commission was charged with the responsibility for establishing written criteria upon which to base a determination of an "extraordinary nuclear occurrence." These criteria are found in 10 C.F.R. Sec. 140.81-85 (1979).

Regulatory Commission (NRC). If the Commission determines an event to be "non-extraordinary," liability is determined under traditional tort law.

The Price-Anderson Act was amended in 1968, to increase the amount of liability insurance available to 82 million dollars, and again in 1972 to raise the private coverage to 95 million dollars. In both amendments, the government's indemnity exposure was decreased by an amount equal to the increase in private liability coverage, and aggregate coverage was maintained at a ceiling of 560 million dollars.

Amendments Enacted in 1975

In 1975 Congress passed a bill which extended the Price-Anderson Act for an additional ten-year period to August 1, 1987 (Act of December 31, 1975). The bill provides for two basic changes in the Act. First, there is a provision for the gradual substitution of industry-financed indemnity to replace government indemnity over and above the amount of private coverage available. The second change provides for an eventual increase in the amount of total liability.

These two goals are to be accomplished through a system of "deferred premiums." In the event of an accident causing damages in excess of the amount of private coverage (currently 160 million dollars, as discussed below), each licensee is assessed a deferred premium of between 2 million and 5 million dollars to cover a share of the excess damages (42 U.S.C. Sec. 2210(b) (1976)). Losses exceeding the combined insurance (primary) and deferred premium (secondary) layers of coverage will continue to be covered under NRC indemnity assurances. As new reactors come on-line, the secondary layer of coverage will increase and gradually replace the federal indemnity provisions. Eventually, the federal indemnity exposure will be eliminated entirely, while the liability ceiling will continue to rise in proportion to the number of new reactors.

Current Status of the Price-Anderson Act

The current provisions of the Price-Anderson Act may be summarized as follows:

(1) Each nuclear power plant licensee is required to maintain third party liability coverage up to the maximum amount available from private sources. On May 1, 1979, this amount was increased to 160 million dollars.

(2) The NRC provides indemnity coverage in the amount of 400 million dollars over and above the amount of private insurance available.

(3) Under the deferred premium plan, the government indemnity exposure will eventually be eliminated and the ceiling on liability will be increased.

(4) The Act limits the liability of all parties to the accident to a total of 560 million dollars.

(5) If an accident is determined by the NRC to be an "extraordinary nuclear occurrence," all legal defenses to liability are waived. This, in effect, establishes strict liability for nuclear catastrophes.

(6) The Act provides for the prompt settlement of claims and immediate partial payment.

THE INSURANCE INDUSTRY'S VIEW

Managing Nuclear Liability Risks

As mentioned above, in 1957 the insurance industry was unsure of the proper premium charge for nuclear liability insurance. Therefore, the underwriters developed a plan which would base the premium on the loss experience of the industry as a whole. Under this plan, called the credit rating plan, approximately 73 cents of every dollar of premium received is held by the insurance pools in a special fund. If this money is not used to pay losses, it is returned to the insured party in the eleventh year after it is received (Marrone 1977, p. 609). Under this arrangement, the insurance pools refunded approximately 13 million dollars from the fund between 1967 and 1978 (National Underwriter, April 13, 1979).

The insurance offered to the nuclear industry is especially remarkable in view of the premium for coverage offered. For example, in 1976 the insurance pools collected a total of 32 million dollars in premiums for 300 million dollars in capacity offered, giving a ratio of roughly 1:10. In comparison, the airline industry was offered similar capacity, but the total annual premium collected was in excess of 300 million dollars, giving a ratio of about 1:1 (Marrone 1977, p. 608). One reason for the low rates offered to the nuclear industry was the excellent safety record of nuclear facilities prior to the accident at Three Mile Island. Between 1957 and 1978, a total of only $623,000 was paid out in claims and claim expenses (National Underwriter, April 13, 1979).

Coverage Offered

At present there are three insurance pools offering protection for nuclear facilities. They are Mutual Atomic Energy Liability Underwriters (MAELU), American Nuclear Insurers (ANI), and the Mutual Atomic Energy Reinsurance Pools. Two types of coverage are offered. The first type is third party liability insurance which covers the operator of the nuclear facility, the suppliers and contractors, and any other party which might be held liable for a nuclear accident. The second type of insurance covers damages to facilities on an "all-risk" basis.

Insurance coverage for the Three Mile Island facility was provided by ANI and MAELU. The maximum liability of these two pools in connection with the accident at TMI is 140 million dollars (since the 160 million dollar liability limit did not go into effect until May 1, 1979). Of this amount, ANI is responsible for 108.5 million dollars; MAELU's share is 31.5 million dollars. After reinsurance with foreign firms, such as Lloyd's of London, the net liability of the two pools is 57.8 million dollars for ANI and 16.8 million dollars for MAELU (Bardes 1979).

Under the credit rating plan, the two pools had placed approximately 73 percent of the collected premiums into a reserve fund which could only be used to pay incurred losses or returned to the insured parties after the ten-year experience period had expired. If the losses incurred by ANI and MAELU exceed the 74.5 million dollars in the reserve fund, a portion of the excess loss will be assigned to each member and reinsurer in the pools (Bardes 1979).

As discussed above, the deferred premium arrangement makes each reactor operator liable for up to 5 million dollars in the event of an accident causing damages in excess of the primary layer of coverage. At the request of Congress, the insurance pools have created a 30 million dollar contingent liability fund to cover any defaults in payment by the licensee.

Finally, ANI provides facilities insurance totaling 300 million. Hence, the insurance coverage for an accident at a nuclear power plant may be summarized as follows: (1) third party liability coverage—160 million dollars (140 million dollars at the time of TMI); (2) facilities coverage—300 million dollars; (3) deferred premium coverage—up to 340 million dollars; (4) government indemnity coverage—up to 60 million dollars; (5) potential liability of insurance pools for licensee default on deferred premium—30 million dollars. Stated alternatively, the insurance pool is potentially liable for up to 490 million dollars, while the government's liability has been reduced to 60 million dollars, a decrease of 440 million dollars since 1957.

LIABILITIES RESULTING FROM THREE MILE ISLAND

Facilities Losses

In August 1980 William G. Kuhns, Chairman of General Public Utilities, announced that the estimate of repair costs is 760 million dollars. GPU believes that the repair will take up to 7 years to complete (New York Times 1980b). To meet the repair costs, GPU is relying on the 300 million dollars of facilities insurance it carried with ANI. Funding for the remaining costs is still in question. There has been some talk of asking the federal government for assistance in the form of a research grant to study the problems associated with decontaminating a reactor facility following an accident (Business Week, July 30, 1979).

In other cost-cutting measures taken by GPU to reduce the financial impact of the accident, the utility has been forced to stop work on two new plants in which it had invested hundreds of millions of dollars. In addition, GPU has been forced to cut its dividend in half and reduce its staff by 600 positions (Business Week, July 30, 1979).

Off-Site Losses

Within hours of the accident at Three Mile Island, ANI set up an emergency claims center to issue payments to residents who were forced to leave as a result of Governor Thornburgh's request for a partial evacuation. The emergency payments were available only to those families with pregnant women or school-age children, the two groups believed to be most susceptible to the radiation released from the crippled reactor (Business Insurance, April 16, 1979). The payments, averaging between $50 and $750 per family, totaled over $600,000 in the first week alone (Business Insurance, April 16, 1979). By the time the crisis was over, 2800 families within a five-mile radius of the plant had been compensated with the total payments amounting to approximately 1.2 million dollars (National Underwriter, July 27, 1979).

Fortunately, there were few cases of looting and vandalism in the communities affected by the evacuation. Most homeowners' policies have an exclusion clause barring claims based on nuclear reactor accidents and there was some doubt whether losses suffered during an evacuation could be compensated. It is now clear that an exception to the bar would apply in the case of theft and vandalism occurring after a home has been evacuated due to nuclear contamination. In the industry's view, "since the vandalism and theft are not a direct result of the contamination, the nuclear exclusion clause does not apply" (National Underwriter, April 20, 1979).

A major category of off-site claims being considered is losses suffered by businesses that were forced to close during the crisis. Although there is no assurance that these claims will be compensated, the insurance pools have told shopowners and businesses to collect documents to show the amount they could have reasonably expected to make during the time they were forced to close (Business Insurance, April 16, 1979). Farmers in the area who also claim to have suffered financial losses may eventually be compensated as well (New York Times, August 23, 1979). However, the industry has emphasized that all cases involving business losses will have to be considered on an individual basis.

As one would expect, the accident at Three Mile Island has generated a considerable number of lawsuits. Within six months of the incident, twenty-nine class action and specific damage suits had been filed and consolidated for trial purposes in middle district courts. In addition to the complaints brought by individuals, twenty-nine suits have been filed by government agencies seeking recovery for expenses incurred during the crisis (National Underwriter, September 28, 1979).

The suits brought by local residents have listed a variety of charges. One claims that residents of the area now have an increased likelihood of developing cancer as a result of the radiation released into the atmosphere during the accident. The suit seeks to impose a "constructive trust" on the "real and personal property of the defendants 'in a sufficient amount to pay for the costs of the plaintiffs and the class members receiving medical and diagnostic treatment services for the next twenty years'". The complaint further alleges that operation of the plant "'constitutes a continuing and unabated nuisance'", which has "'substantially and permanently disturbed plaintiffs' and class members' peaceful enjoyment of their lands'" (National Underwriter, May 18, 1979).

Other suits have been filed to seek damages for "general physical and emotional injuries" or "psychic damages". These suits are based on the claim that the malfunction of the reactor caused mental anguish resulting from the fear of being injured by nuclear radiation. Naturally, the plaintiffs in these cases will bear the same burden of proof required in any case involving mental anguish injuries.

The outcome of these suits is affected by the fact that the NRC has determined that the Three Mile Island accident was not an "extraordinary nuclear occurrence" (ENO), since the radiation releases were below established criteria for declaring an ENO. As a result, the waiver of defense provisions of the Price-Anderson Act cannot be invoked. Liability for the suits must then be determined on the basis of traditional tort law.

Replacement Power Costs

In order to restore electrical service to the communities previously served by the Three Mile Island plant, GPU was forced to purchase replacement power from neighboring utilities. It is estimated that GPU is currently spending about $600,000 per day to replace power previously supplied by the Unit II reactor, the site of the March 28 accident. An additional $500,000 per day is required to replace power from the Unit I reactor, which has also remained closed since the date of the accident (National Underwriter, May 4, 1979). Thus GPU is paying a total of approximately 1.1 million dollars per day for replacement power costs. While there is reason to believe that the operational Unit I reactor will be placed on-line before the end of 1981, replacement power costs for Unit II alone could run as high as 900 million dollars, depending on the price and availability of oil over the four years following the accident.

POST-TMI MEASURES TO COMPENSATE LOSSES FROM NUCLEAR ACCIDENTS

Replacement Power Costs and First-Party Coverage

To deal with the staggering losses associated with purchasing replacement power, the nuclear industry has announced plans to form an insurance pool to provide funds to utilities whose service has been interrupted by a nuclear accident (Washington Post, September 22, 1979).

The National Association of Insurance Commissioners (NAIC) recently requested that the nuclear industry supply information aimed at determining whether accidents involving nuclear reactors can be covered adequately under first-party property insurance (National Underwriter, June 24, 1979). The NAIC noted that it had been unsuccessful in obtaining industry estimates of the costs of insuring property losses under first-party insurance programs and that this failure was due to several factors, including:

(1) The uncertainty surrounding the probability of a nuclear accident.

(2) The innumerable variables that influence the extent and nature of personal injuries and property damage arising from nuclear accidents.

(3) The adverse selection difficulties inherent in the concept of insuring nuclear accident losses under first-party insurance coverage.

(4) The conflict between the Price-Anderson Act's third-party liability system and the proposal to insure excess nuclear losses under first-party insurance coverages.

Under the system proposed by the NAIC, an entirely private catastrophic risk insurance program would be substituted for the current nuclear accident compensation program contained in the Price-Anderson Act.

SUMMARY AND CONCLUSIONS

The Price-Anderson Act

The Price-Anderson Act was enacted with the dual purpose of encouraging nuclear power development and protecting the public from the substantial losses that could result from a nuclear catastrophe. There is little doubt that the goal of promotion has been achieved. Indeed, critics of the Act charge that the federal indemnity provisions amount to a subsidy of the nuclear industry. This characterization is vigorously contested by proponents of the legislation on the grounds that the industry pays fees for the indemnity protection (this fee is currently $30 per year per thousand kilowatts of thermal energy capacity) (42 U.S.C. Sec. 2210(f) (1976)). Nevertheless, it is clear that the net effect is a subsidy, even though it is achieved by removing a burden, rather than by providing direct revenues.

The need for continuing the role of Price-Anderson as a promotional mechanism is unclear. Although the legislation was considered to be essential to the early development of civilian nuclear energy, some industry spokesmen have said that they would continue to build nuclear facilities even if there were no limitation on liability. Yet, many commentators feel that this is an overly optimistic assessment. They argue that removing the liability limit would effectively deal a death blow to the nuclear industry.

If nuclear power development were to continue in the absence of liability limitations, it would undoubtedly take on a different complexion. Social costs which have been externalized by the Price-Anderson Act would have to be internalized by the utility and would, therefore, change the economic bases for many decisions. One example would be the siting of nuclear facilities. With the present limitation on liability, utilities are free to site facilities near major population centers, thus taking advantage of savings resulting from shorter transmission distances. On the other hand, if there were no liability ceiling, it is doubtful that the savings realized from shorter transmission distances could balance the potential liability associated with locating the plant near a major population center.

A major criticism of the Price-Anderson Act has been the claim that 560 million dollars is an insufficient amount to fully compensate the public in the event of a serious nuclear accident. Many critics argue that the limitation on liability should be lifted entirely. However, it should be noted that the right to sue for an amount above the present statutory ceiling would not necessarily guarantee the ability to collect. The nonspecific nature of many claims for radiation-induced damages could present insurmountable barriers to recovery. Furthermore, it might take litigants many years to reach an adjudication, which could bankrupt the utility and still provide inadequate relief.

The Price-Anderson waiver of defense provisions is designed to eliminate many of the difficulties encountered by claimants who must establish a causal link between exposure to radiation and their injury. But these waivers must be preceded by an NRC determination that an "extraordinary nuclear occurrence" has taken place. The NRC has determined that the accident at TMI was a "non-extraordinary" occurrence, since the radiation releases were below the established guidelines. Therefore, claimants in that case are required to establish liability under traditional tort law.

TMI Losses

Perhaps the most pressing financial needs during the TMI crisis were the emergency payments to families who left their homes in response to Governor Thornburgh's recommendation for a partial evacuation within a five-mile radius of the plant. It appears that ANI responded to this need in a prompt and efficient manner.

Restoration of the TMI plant facilities will be a very costly, time-consuming process. A portion of the costs will be covered by insurance. However, the source of the uninsured portion of the costs remains to be determined. The Public Utilities Commission in Pennsylvania has ruled that repair costs cannot be passed to consumers (New York Times, May 10, 1980).

Finally, the cost of replacement power has surfaced as a major concern regarding post-accident recovery. It is estimated that GPU could spend well over 1 billion dollars in replacement power costs over the four years following the accident. The Pennsylvania Public Utilities Commission has allowed the utility to institute a temporary 111 million dollar-per-year rate hike to cover some of the costs of buying replacement power. In addition, the proposed industry-financed plan for dealing with these costs is intended to lessen the impact of prolonged shutdowns on the utilities.

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V. TECHNICAL CONSIDERATIONS

Several technical procedures and systems provide vital inputs for nuclear accident preparedness and management. The papers in this Section describe technical bases for setting planning and reliability requirements, data storage and retrieval mechanisms to facilitate learning from past accidents, rapid dosimetry assessments of nuclear accident health effects, and noise diagnosis in support of early accident management.

19

TECHNICAL ASPECTS OF NUCLEAR POWER PLANT RELIABILITY AND SAFETY

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INTRODUCTION

The development of nuclear energy has been accompanied by an increased awareness of the importance of safety in nuclear power plants. The radioactive material accumulated during the operation of nuclear reactors presents a potential danger for the environment. Ensuring the safety of a nuclear power plant, i.e., preventing the melting of the nuclear reactor core, and preventing the release of dangerous radioactive material into the environment, is a complicated problem with no immediate solution.

A nuclear power plant, with all its components, may be considered a system whose purpose is to produce electrical energy. In this paper a systems approach will be used to provide a framework for the comprehensive analysis of the problem of nuclear power plant safety. The principles of the systems approach may be conceived as follows: (1) the system is composed of elements; (2) the elements of the system are interconnected, and (3) the elements influence one another. On the basis of these principles, two major goals of one procedure of analysis, which may be called 'systemization,' may be outlined: first, identification of the system and decomposition of the system into elements; second, identification of the connections between elements and the character of these connections.

SYSTEMIZATION

A nuclear power plant should be considered a system encompassing specific devices and pieces of machinery that perform certain functions in a given chronological sequence. Thus it is useful to systematize such a plant structurally, functionally, and chronologically.

A *structural systemization* identifies the location of every piece of equipment in the system. This makes it possible to classify elements of the same type, to develop uniform requirements to be imposed on different classes of elements, and to group all equipment into classes or categories on the basis of their requirements for reliability. In the case of Category I equipment, such as pipes, failure can lead to large radioactive releases in the primary circuit. Category II equipment is less important for safety, but of great importance for reliable electricity generation. Primary circuit circulation pumps fall into this category. Failure of equipment in Category III does not interrupt the generation of electricity. Auxiliary equipment in the secondary circuit is an example of Category III equipment. An example of a structural systemization is given in Figure 1.

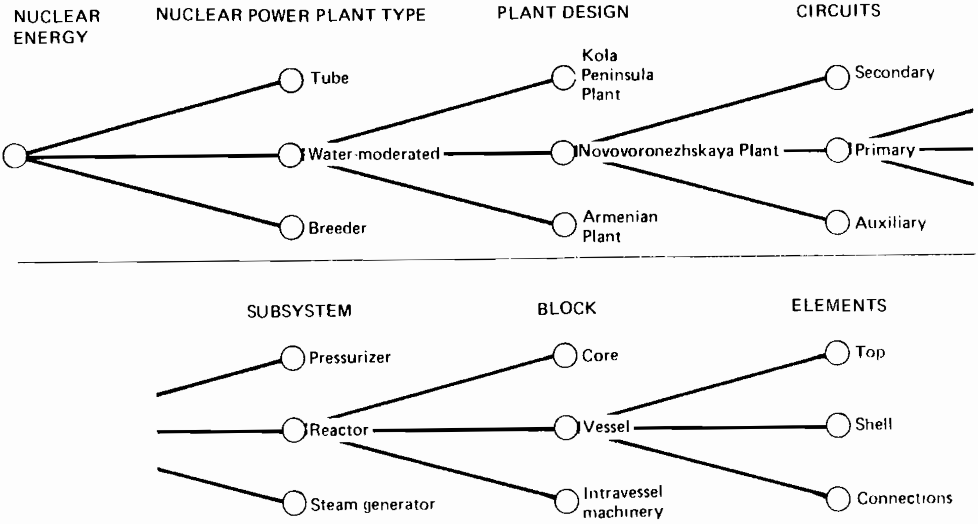

Figure 1. An example of a structural systemization of a nuclear power plant.

In a *functional systemization*, another three categories of equipment, which perform certain functions and provide safety under unfavorable conditions, are identified. Category I equipment ensures the safety of the power generation process. This category represents the first level of safety equipment in nuclear power plants. Category II safety devices operate when equipment failures or external events, such as earthquakes, occur. These safety devices make it possible to reverse the initial development of an accident and to maintain fuel elements in operational status. This category represents the second level of safety equipment for the plant. Category III equipment ensures safety in the event of an accident. These devices represent the third level of safety equipment preventing radioactive releases.

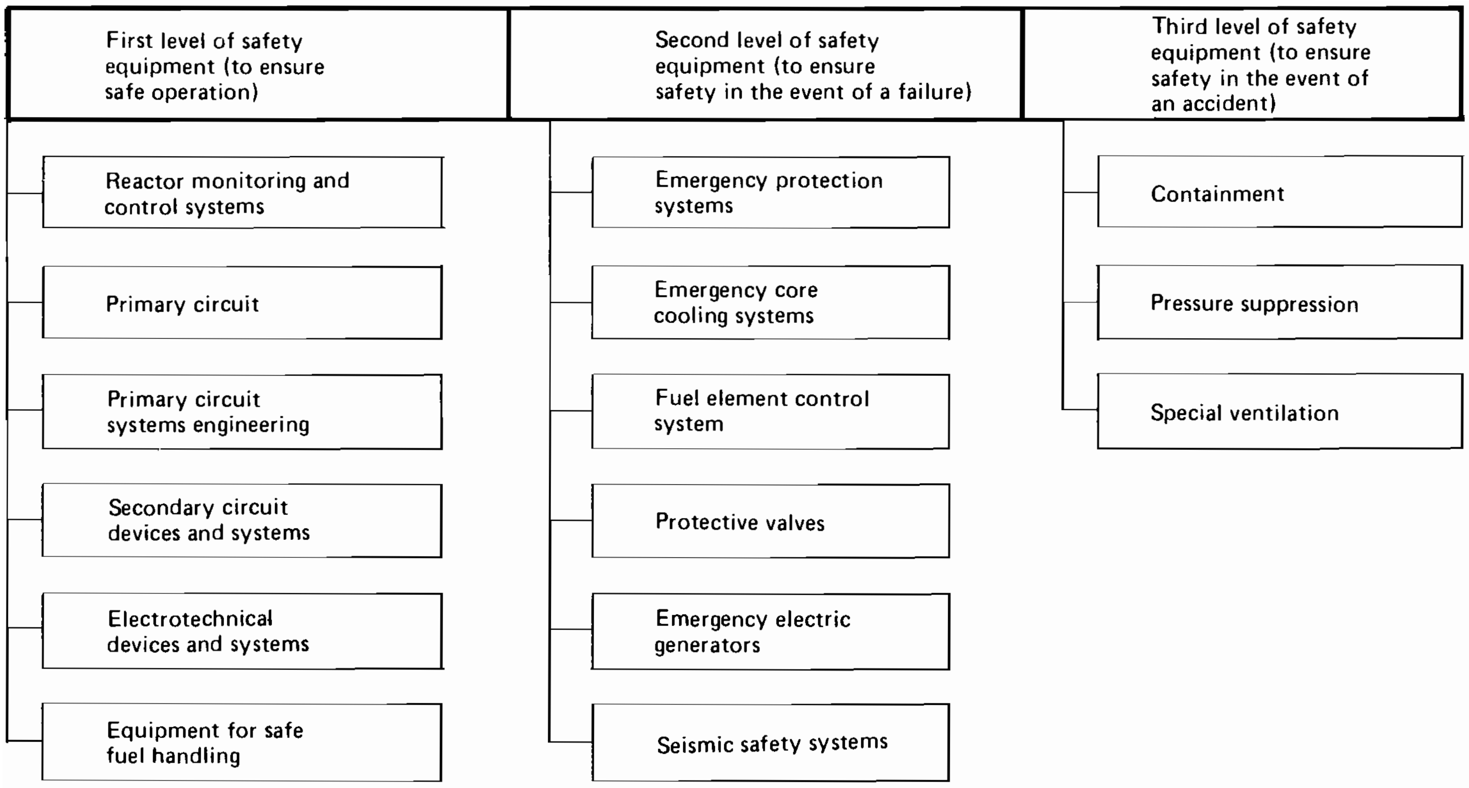

Figure 2. An example of a functional systemization of a nuclear power plant.

An example of a functional systemization is presented in Figure 2. Machinery in each category has specific reliability requirements, and these should be taken into account during design, production, and installation. Under normal operating conditions this functional systemization provides a basis for developing different methods of testing machinery with special attention to minimizing the time required for testing. The functional systemization could also be used as a basis for optimizing atomic power plant safety, taking into account economic factors. Generally this systemization could be used to demonstrate the necessity or sufficiency of proposed safety measures.

A *chronological systemization* may be used to describe the stages of construction and maintenance of a system. These stages include design, fabrication, installation, start-up and adjustment, operation, and repair, as shown in Figure 3. For each stage requirements for the safety of equipment and subsystems may be studied, taking into account a plant's specific features.

At the design stage primary consideration is given to the radiation-physics, thermohydraulics, and mechanical integrity of the reactor and its facilities under normal, transitional, and emergency conditions. It is important to ensure high quality, which in turn ensures plant safety, at the fabrication stage. Quality control before the installation phase precludes the delivery of defective machinery.

Under operating conditions some structural changes appear in materials. These changes, caused by vibration, corrosion, and radiation, can lead to equipment failure. For this reason special attention should be paid to operational monitoring methods, especially remote monitoring (such as ultrasonic, acoustic, and emission monitoring). Structural and functional systemization makes it possible to determine the most important sites for monitoring, for example, where there is a concentration of stress in equipment in structural categories I and II.

SYSTEMIZATION OF SAFETY AND RELIABILITY REQUIREMENTS FOR NUCLEAR POWER PLANTS

General requirements. Every operating condition of a nuclear reactor has a particular nuclear or thermotechnical character, each associated with specific safety problems. In the event of a failure, the parameters describing every process should be maintained within given safety limits. Safety limits might be defined in terms of the following factors:

- neutralization of the consequences of a failure while maintaining the operational status of the plant;
- prevention of the development of a failure into an accident; and
- prevention of radioactive releases.

In the case of unfavorable changes in operating conditions, all safety measures that are taken should be consistent with the

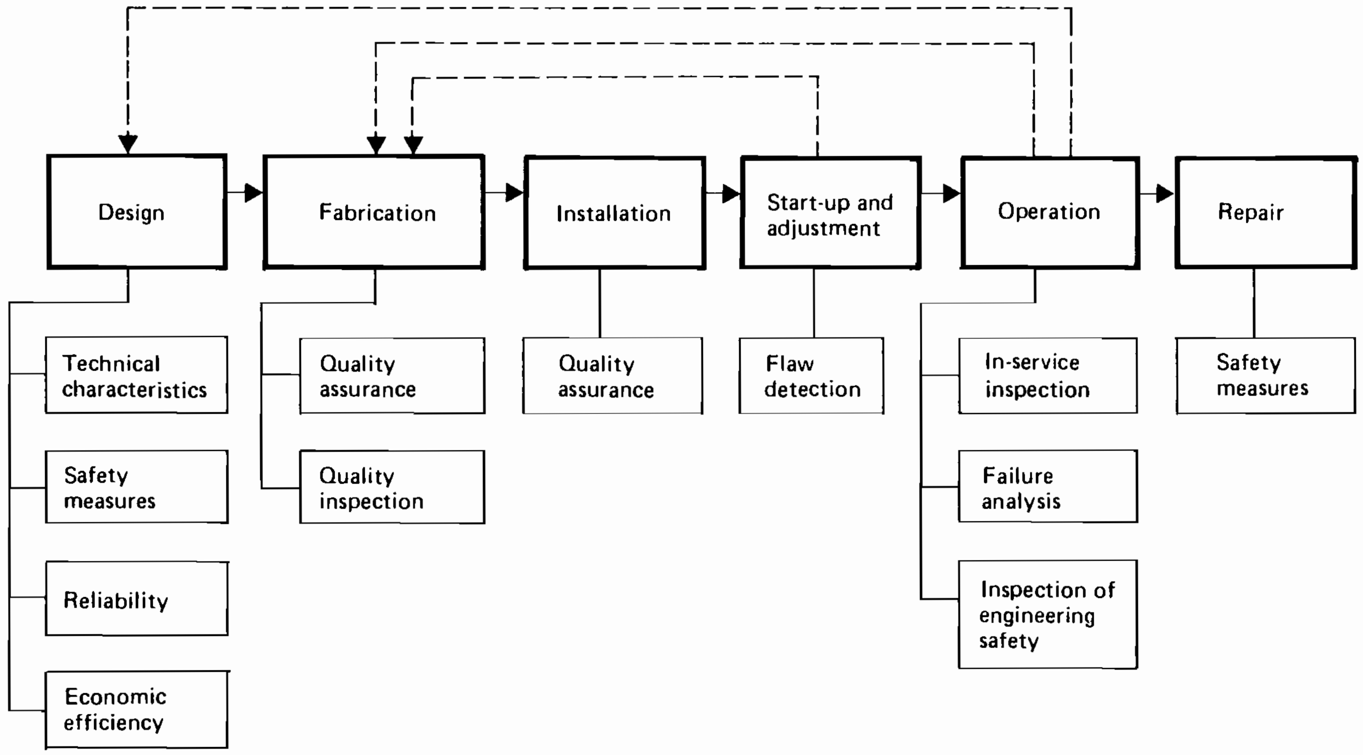

Figure 3. An example of a chronological systemization of a nuclear power plant.

general safety requirements for the power plant as a whole. Safety measures achieved by varying operating conditions (downrating, controlling the values of some parameters, etc.) are economically advisable. Implementation of technical safety measures to keep a plant operational in the event of large-scale failure would be too complicated and expensive. Nontechnical safety measures should be used for protecting the population and environment from radioactive releases. These considerations should enter into the determination of safety requirements for nuclear power plants.

As discussed above, at every stage in the development and operation of a nuclear power plant careful attention should be paid to the safety of systems and equipment whose failure could lead to an accident. Because of the small probability of such failures, safety requirements are not necessarily consistent with requirements for reliability.

Requirements for safety measures and their cost should be determined by the scale of failure. In every emergency case a "limited failure mode"—not unlike a fuse in an electrical circuit—should be established, with consequences that can definitely be localized and limited by safety measures. This concept is related to the notion of a "maximum rated accident" (MRA). The MRA for a water-moderated reactor, for example, is a failure in the primary circuit, an event with an estimated annual probability of 10^{-4}. Safety measures for that event are aimed at preventing melting of the core and metal—water reactions. This would make it possible to carry out post-accident repair of the core and intravessel machinery. These measures would prevent radioactive releases to the environment if fuel elements are damaged (which would occur if temperatures become higher than 1200-1300 °C). A possible failure of the reactor vessel is not considered in the planning of safety requirements because of its small probability (10^{-6} per year). Siting nuclear power plants at distances of 40-50 km away from densely populated areas is a measure that limits the consequences that could stem from accidents exceeding a MRA in scale.

Safety requirements during special operations. Safety problems associated with charging the core, starting the reactor, changing fuel elements, and other special operations must be handled through technical measures and carefully planned procedures.

Requirements for radiological safety. Fission products are the main sources of radioactivity in a plant. The hermetic cladding of fuel elements represents the first safety barrier for fission products. Still, the high pressure caused by gaseous fission products, thermal fatigue, and superheating produces cracks and even perforations in the fuel cladding. This could result in inadmissible levels of radioactivity in the primary circuit coolant. For this reason it is required that no more than 1% of fuel elements have microfissures and no more than 0.1% have perforations. If these requirements are met, increased specific radioactivity in the primary circuit coolant due to leaking should not exceed 0.14 curie/liter.

The integrity of the primary circuit represents the second barrier for radioactivity. This barrier could be damaged by increased coolant pressure and vibration, together with inter-crystal corrosion. The hermetic safety jacket of the reactor is the third barrier of radiological protection. It provides simultaneous protection from both external and internal mechanical effects.

Reliability requirements. Economic factors should be taken into consideration in determining the requirements for reliability. On the one hand, high reliability leads to a high load factor. But, on the other hand, expenditures connected with increasing reliability lead to higher capital cost. It follows that there is an optimal level of reliability for a plant that is a function of the economics of increased load factor vs investment in competition with other energy sources. Optimal levels of reliability can be determined by a complex technical and economic analysis. Relationships between safety, reliability, and several other factors discussed in this paper are presented in Figure 4.

The general concept of plant reliability includes operational reliability, lifetime of the plant, and maintainability. Operational reliability refers to the probability of operating without failure throughout a reference period of time. The overall reliability of a nuclear power plant is the aggregated reliability of all systems and equipment, especially those that play a primary role in the operation of the plant.

Although the general reliability of a plant can only be estimated on a relative basis, such an estimate yields important information. This information makes it possible to determine the optimal structure of the reactor, to identify systems and equipment with insufficient reliability, to compare power plants that are still in the design phase with operating plants, and to identify equipment requiring improved production technology. Special emphasis should be placed on the thermomechanical reliability of the nuclear reactor core, which is characterized by particular parameters. In the case of water-moderated reactors the most important of these parameters relate heat emission characteristics of the fuel elements to maximum energy releases under various operating conditions. The reliability of fuel elements in the core is determined by the ratio of critical thermal flux to the maximum flux sustainable by the fuel elements. This value should take into account local irregularities in core parameters.

CLASSIFICATION OF EMERGENCY PROCESSES

An analysis of emergency processes is required to evaluate the safety of a nuclear power plant. This analysis makes it possible to determine the necessity and sufficiency of safety measures and to specify safety requirements. Emergency processes have a complicated character, because failure in one system might lead to failure in another, or two failures may coincide by chance.

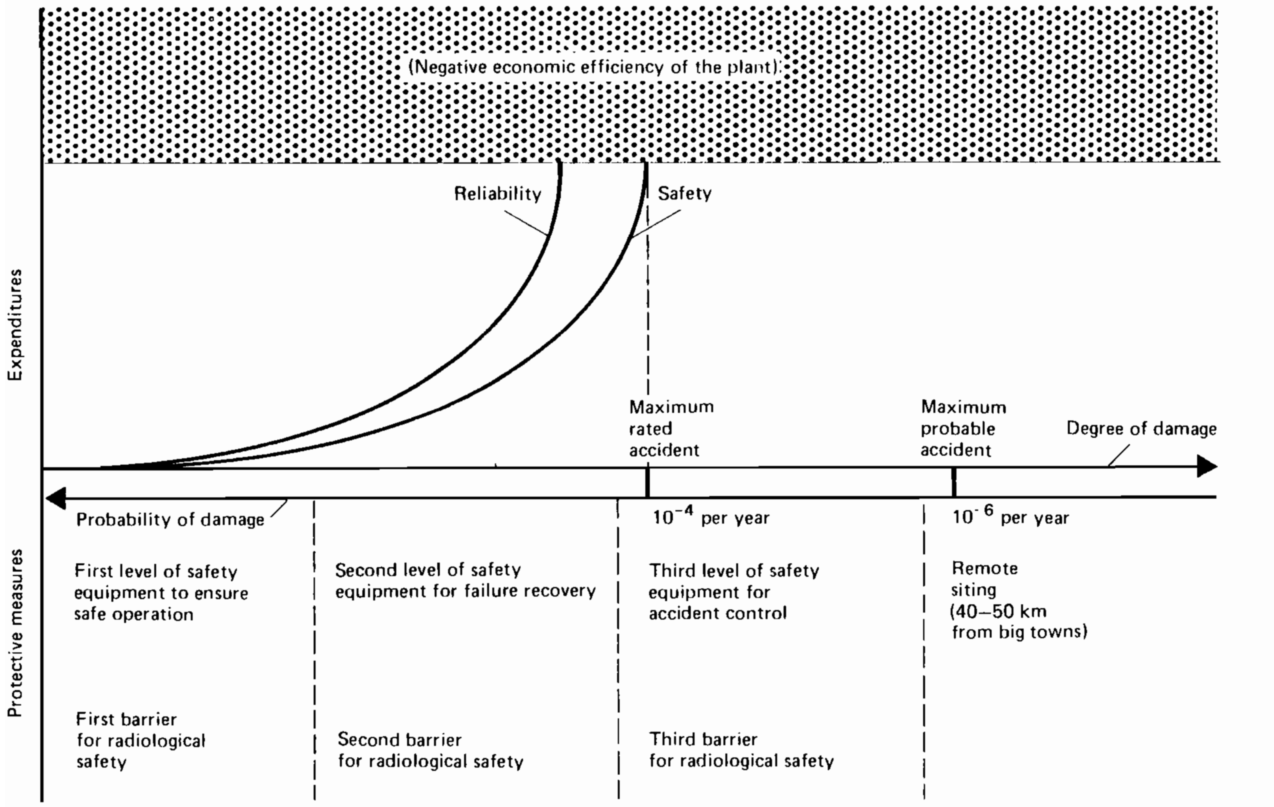

Figure 4. Relationships between safety, reliability, and factors such as economic efficiency in a nuclear power plant.

Calculations describing various emergency processes can be used to specify the range of values of important parameters; this information can be stored in a computer memory and retrieved in the event of an emergency. Possible emergency processes may be divided into the following groups:

- emergency processes involving variations in reactivity, including trouble with the control system, an unexpected change of the boron concentration in the primary circuit coolant, and connection of a nonoperational (cold) loop;
- emergency processes connected with the loss of primary circuit coolant flow;
- failure in the primary circuit, including a break in the main circulation pipe;
- failure in the secondary circuit, including a break in the main steam condensor;
- loss of power available to the plant.

The characteristics of the emergency process very much depend on the level of energy flux and the type of reactor. In water-moderated reactors the energy accumulated in the primary circuit presents a major danger, on the order of about 10^8 kilojoules.

The above discussion represents an initial attempt to apply a systems approach to problems of assuring the safety of a nuclear power plant.

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20

THE CAUSE—CONSEQUENCE DATA BASE: A RETRIEVAL SYSTEM FOR RECORDS PERTAINING TO ACCIDENT MANAGEMENT

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INTRODUCTION

The events at Three Mile Island-Unit 2 on March 28, 1979 have profoundly affected our thinking about the safety of nuclear reactors. A question we must now ask is, How can we effectively learn as many lessons as possible from this mishap?

Since letters were invented several thousand years ago, human beings have been documenting their experiences. Relevant documents have been retrieved and examined over and over again to facilitate creative thinking to cope with new situations. Since the TMI accident, many investigators, including those representing the Nuclear Regulatory Commission (NRC) and those serving on The President's Commission on the Accident at Three Mile Island, have evaluated the events at TMI. Reports of several investigations are already available (President's Commission 1979; USNRC, July 1979; USNRC, August 1979; Spectrum 1979). How can we learn systematically and effectively from these documents? Conventional methods that simply provide an overview or summary of the various reports should be replaced by new approaches.

This paper describes a proposal to store in a data base important paragraphs from reports of investigations into many types of accidents. The data base is to handle not only reports on TMI, but also reports on other events at nuclear reactors, chemical plant explosions, earthquakes, hurricanes, fires, and so forth.

Every paragraph of the reports that contains ideas of importance becomes a record in the data base. Each such paragraph, consisting of about 5 to 10 sentences, describes either causal relations between events or recommendations for accident management. Several key words (for example, "emergency core cooling system," "operator," "control room," or "evacuation") are attached to each record, corresponding to words and phrases appearing in the sentences.* These key words are stored in the data base together with the paragraphs. Any records relevant to a user's key words can be printed out on an on-line typewriter, in response to the user's requests. We have named this retrieval system the "Cause—Consequence Data Base," since it deals mainly with causal relations and recommendations rather than quantitative data describing the reliability of systems.

The data base currently uses software called IRIS, an Interactive Retrieval Information System (Toliver 1979). IRIS permits us to (1) create sets of records relevant to users' key words; (2) review an alphabetic index of all such key words; (3) apply logical operators (AND, OR, NOT) in order to create sets of records that are subsets of the file with the specified characteristics; and (4) print out these subsets in a variety of formats.

The Cause—Consequence Data Base spurs the creativity of people in charge of accident prevention and preparedness. Discussions of safety problems that draw on the data base can yield fruitful results, for it is possible to consult specific records on accidents that actually occurred. The data base could also become a basic tool for risk analysis, aiding in the construction of event trees and fault trees.

The accumulation of records for the data base was started in November 1979. In January 1980 we had 125 records; the first 100 records came from the Kemeny report (The President's Commission, October 1979), and 25 records were extracted from a special issue of Spectrum (Spectrum 1979). This amount of data is sufficient for demonstrating the potential features of the data base, as is shown in the sample search of the data base provided in the Appendix at the conclusion of this paper. We are constantly accumulating new records; as of February 1981 records extracted from reports on 40 nuclear reactor accidents were stored in the data base. These 40 accidents are described in Bertini (1980).

THE DATA BASE—AN AID FOR ACCIDENT MANAGEMENT

The data base as a source of knowledge. The Cause—Consequence Data Base can help people think creatively. For example, records @ 0067 and @ 0110, reproduced in the Appendix at the end of this paper, might spur plant designers to improve the simulators used for operator training.

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*The key words can be controlled by a thesaurus. For instance, the key words GAUGE, INDICATOR, AND RECORDER are listed in an entry entitled SENSOR. The thesaurus not only reduces the amount of labor required for the attachment of key words, but also increases the users' chances of finding relevant records.

The data base prevents safety and reliability theories from remaining academic exercises. Researchers in universities and industries can use output from the retrieval system to identify many important unsolved problems.

Scenario writing and the data base. Modern risk analysis starts with writing scenarios that describe the development of events. An example of this is the set of event trees that played a fundamental role in the Rasmussen Report (USAEC 1975). Scenarios similar to event trees are important for operator training, evacuation planning, and design of safety systems and emergency procedures.

The TMI accident has revealed that risk analysis based on a single failure is insufficient. Scenarios useful for operator training should usually contain multiple failures. The problem is to write realistic scenarios without overlooking crucial events. Here the Cause—Consequence Data Base can be of help. For example, records relevant to the key word "MAINTENANCE" would show which events may follow a maintenance error. If the consequences of this error involve valve failures, the key word "VALVE" can be applied to further develop the scenarios.

Fault tree construction and the data base. An event tree is based on a prospective analysis that involves searching for possible consequences of events. In contrast, a fault tree involves a retrospective analysis of an event of importance. The event is analyzed top-down, with a search for possible causes. Events isolated at the bottom of the tree are ultimate causes and are called basic events. Fault trees are fundamental tools for qualitative and quantitative risk analysis.

One of the drawbacks of fault tree analysis is that too much time must be spent for the heuristic construction of the fault tree. The Cause—Consequence Data Base can alleviate this difficulty. Possible causes of a given event can be obtained from the data base, making it easier to construct the trees without missing important causes. For instance, a dangerous ECCS failure may be analyzed retrospectively by examining records @ 0011, @ 0015, and @ 0087, as reproduced in the Appendix.

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APPENDIX: A SAMPLE SEARCH OF THE DATA BASE

The sample search of the Cause—Consequence Data Base presented in this Appendix had two objectives:

— To print out records that describe relationships between emergency core cooling systems (ECCS) and operators.

— To print out records relevant to the training of operators on simulators.

In the computer printout below a question mark "?" follows each user command. The commands are also underlined to distinguish them from data-base output. A step-by-step explanation of the search procedure follows the printout.

A Sample Printout:

```
? BEGIN

SET   COUNT   DESCRIPTION
***   *****   ***********

? SELECT ECCS
 1        2   ECCS

? EXPAND ECCS

 REF     DESCRIPTION                         CNT   REF
 ***   ***************************           ***   ***
 82      KEY:  DOWNTIME                        1     0
 83      KEY:  DRAIN-PIPE                      2     0
 84      KEY:  DRAIN-TANK                      2     0
 85      KEY:  DRIVING-SAFETY                  1     0
 86      KEY:  EARLY-STAGE                     1     0
```

```
ECCS
 87     KEY:  ECCS                          2    0
 88     KEY:  ECONOMIC-CONSIDERATION        1    0
 89     KEY:  ECS                           3    0
 90     KEY:  ELECTOMATIC-SAFETY-VALVE      1    0
 91     KEY:  ELECTRIC-GENERATOR            1    0
 92     KEY:  ELECTRICAL-FAILURE            1    0

? S ECS
 2        3    ECS

? DESPLAY
ERR17:  INVALID ARGUMENT

? DS

SET   COUNT   DESCRIPTION
***   *****   ***********
 1      2     ECCS
 2      3     ECS

? COMBINE 1 OR 2
 3   5 1 OR 2

? S OPERATOR
 4        45    OPERATOR

? COMBINE 3 AND 4
 5   3 3 AND 4

? PRINT 5/4/1-3

ACCN= 54
@ 0011
OTHER INVESTIGATIONS HAVE CONCLUDED THAT> WHILE EQUIPMENT FAILURES
INITIATED THE EVENT> THE FUNDAMENTAL CAUSE OF THE ACCIDENT WAS
OPERATOR ERROR.  IT IS POINTED OUT THAT IF THE OPERATORS (OR
THOSE WHO SUPERVISED THEM) HAD KEPT THE EMERGENCY COOLING SYSTEMS
ON THROUGH THE EARLY STAGES OF THE ACCIDENT> THREE MILE ISLAND
WOULD HAVE BEEN LIMITED TO A RELATIVELY INSIGNIFICANT INCIDENT.
WHILE WE AGREE THAT THIS STATEMENT IS TRUE> WE ALSO FEEL THAT
IT DOES NOT SPEAK TO THE FUNDAMENTAL CAUSES OF THE ACCIDENT.

ACCN= 69
@ 0015
A SENIOR ENGINEER OF THE BABCOCK & WILCOX COMPANY (SUPPLIERS
OF THE NUCLEAR STEAM SYSTEM) NOTED IN AN EARLIER ACCIDENT>
BEARING STRONG SIMILARITIES TO THE ONE AT THREE MILE ISLAND>
THAT OPERATORS HAD MISTAKENLY TURNED OFF THE EMERGENCY COOLING
SYSTEM.  HE POINTED OUT THAT WE WERE LUCKY THAT THE CIRCUMSTANCES
UNDER WHICH THIS ERROR WAS COMMITTED DID NOT LEAD TO A SERIOUS
ACCIDENT AND WARNED THAT UNDER OTHER CIRCUMSTANCES (LIKE THOSE
THAT WOULD LATER EXIST AT THREE MILE ISLAND) > A VERY SERIOUS
ACCIDENT COULD RESULT.  HE URGED> IN THE STRONGEST TERMS THAT
CLEAR INSTRUCTIONS BE PASSED ON TO THE OPERATORS.  THIS MEMO-
RANDUM WAS WRITTEN 13 MONTHS BEFORE THE ACCIDENT AT THREE MILE
```

```
ISLAND> BUT NO NEW INSTRUCTIONS RESULTED FROM IT.  THE COMMISSION#S
INVESTIGATION OF THIS INCIDENT> AND OTHER SIMILAR INCIDENTS
WITHIN B&W AND THE NRC> INDICATE THAT THE LACK OF UNDERSTANDING
THAT LED THE OPERATORS TO INCORRECT ACTION EXISTED BOTH WITHIN
THE NUCLEAR REGULATORY COMMISSION AND WITHIN THE UTILITY AND
ITS SUPPLIERS.

ACCN= 457
@ 0087
TWO MINUTES INTO THE INCIDENT> WITH THE PRESSURIZER LEVEL STILL
RISING> PRESSURE IN THE REACTOR COOLANT SYSTEM DROPPED SHARPLY.
AUTOMATICALLY> TWO LARGE PUMPS BEGAN POURING ABOUT 1000 GALLONS
A MINUTE INTO THE SYSTEM.  THE PUMPS> CALLED HIGH PRESSURE
INJECTION (HPI) PUMPS> ARE PART OF THE REACTOR#S EMERGENCY CORE
COOLING SYSTEM.  THE LEVEL OF WATER IN THE PRESSURIZER CONTINUED
TO RISE> AND THE OPERATORS> CONDITIONED TO MAINTAIN A CERTAIN
LEVEL IN THE PRESSURIZER> TOOK THIS TO MEAN THAT THE SYSTEM
HAD PLENTY OF WATER IN IT.  HOWEVER> THE PRESSURE OF REACTOR
COOLANT SYSTEM WATER WAS FALLING> AND ITS TEMPERATURE BECAME
CONSTANT.

? S TRAINING
 6       19    TRAINING

? S SIMULATOR
 7       3    SIMULATOR

? COMBINE 6 AND 7
 8  2 6 AND 7

? PRINT 8/4/1-2

ACCN= 345
@ 0067
A KEY TOOL IN THE B&W TRAINING IS A /SIMULATOR>/ WHICH IS A
MOCK CONTROL CONSOLE THAT CAN REPRODUCE REALISTICALLY EVENTS
THAT HAPPEN WITHIN A POWER PLANT.  THE SIMULATOR DIFFERS IN
CERTAIN SIGNIFICANT WAY FROM THE ACTUAL CONTROL CONSOLE.  ALSO>
THE SIMULATOR WAS NOT PROGRAMMED> PRIOR TO MARCH 28>  TO REPRO-
DUCE THE CONDITIONS THAT CONFRONTED THE OPERATORS DURING THE
ACCIDENT.

ACCN= 620
@ 0110
HAD THE OPERATORS LOOKED AT THE TEMPERATURE GAUGE AND THEN AT
THE REACTOR-COOLANT-SYSTEM PRESSURE RECORDERS> THEN CONSULTED
A STEAM TABLE POSTED BY BABCOCK & WILCOX ON THE SIMULATOR
PANEL> THEY WOULD HAVE KNOWN THAT STEAM WAS FORMING.  THIS
PROCEDURE WOULD HAVE TAKEN 15 SEC.  BUT THERE WERE NO STEAM
TABLES ON THE TMI-2 CONTROL PANELS; NONE WERE CONSULTED BY THE
PLANT OPERATORS DURING THE ACCIDENT; AND THERE IS NO PUBLISHED
EVIDENCE SHOWING THAT THE OPERATORS WERE EVER TRAINED TO USE
SUCH TABLES.

? END

SEARCH SETS SAVED
```

Explanation of the steps in the search:

(1) BEGIN. This command ensures that set numbering begins with "1". A set is a collection of records with specified characteristics.

(2) SELECT ECCS. Records relevant to the key word ECCS are combined into Set 1. The set is composed of two records, as the printout indicates.

(3) EXPAND ECCS. This command helps the user review other key words that may be relevant to the initial key word, i.e., key words are printed that precede or follow the initial key word alphabetically. The list generated by this command in the above printout includes ECS (Emergency Cooling System), which the user should identify as a variant of ECCS. The EXPAND command is useful for finding similar or misspelled words. (A version of the EXPAND command, PIVOT, is also useful for identifying key words in the form of a modifier + noun. This command causes the key words containing a particular noun to be listed in alphabetical order of the modifier.)

(4) S ECS. Records relevant to the key word "ECS" are combined into Set 2. (The SELECT verb is abbreviated to simply "S".) We may observe that 3 records have the key word "ECS".

(5) DESPLAY. Misspelled command. An error message results.

(6) DS. The DISPLAY verb is simplified to "DS". The number of sets created thus far are summarized.

(7) COMBINE 1 OR 2. A new set, Set 3, is created, consisting of all records that contain either ECCS or ECS as a key word. This new set contains five records.

(8) S OPERATOR. Records that have OPERATOR as a key word are formed into Set 4. This set contains 45 records.

(9) COMBINE 3 AND 4. Three records that satisfy the first objective of our search, i.e., that describe relationships between operators and emergency core cooling systems, are combined into Set 5.

(10) PRINT 5/4/1-3. The three records in Set 5 are printed out. The number 4 means that the full output of the records should be listed.

(11) S TRAINING. Set 6 contains 19 records pertaining to the key word TRAINING.

(12) S SIMULATOR. Set 7 contains 3 records relevant to the key word SIMULATOR.

(13) COMBINE 6 AND 7. Two records that fulfill the second objective of our search, i.e., that describe operator training on simulators, are combined into Set 8.

(14) PRINT 8/4/1-2. Both records in Set 8 are printed out.

(15) END. The sets generated so far are saved for the next session, and the present session is terminated.

21

THE OFF-SITE RADIATION MONITORING SYSTEM SERVING THE PAKS NUCLEAR POWER STATION IN HUNGARY

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INTRODUCTION

If a major radiological accident, e.g., a design basis accident, occurs at a nuclear power station and a large amount of radioactive material is released into the environment, utilities and local government authorities must make decisions very rapidly to protect the endangered population. In such a situation, radiation monitoring and reporting undertaken in the shortest possible time are of paramount importance as instruments for minimizing the effects of the accident.

This paper describes the main characteristics of the off-site radiation monitoring system developed for the first Hungarian nuclear power station, Paks. The focus of the discussion is on accident management at the plant in the case of a maximum credible accident (MCA).

MAIN CHARACTERISTICS OF THE STATION

The Paks nuclear power station is located on the right bank of the Danube River 110 km from Budapest, as shown in Figure 1. The town nearest the site is Paks, with a fixed population of about twenty thousand people. The villages in the vicinity are less populated, each with only a few thousand inhabitants.

The Paks station is at present still under construction; its capacity is expected to increase from 440 MWe in 1981 to 880 WMe in 1982, 1,760 MWe in 1985, and finally to 3,500-4,000 MWe by 1990. Its highest possible power capacity will range between 5,000 and 6,000 MWe, but fresh water cooling can be provided only up to a capacity of 4,000 MWe.

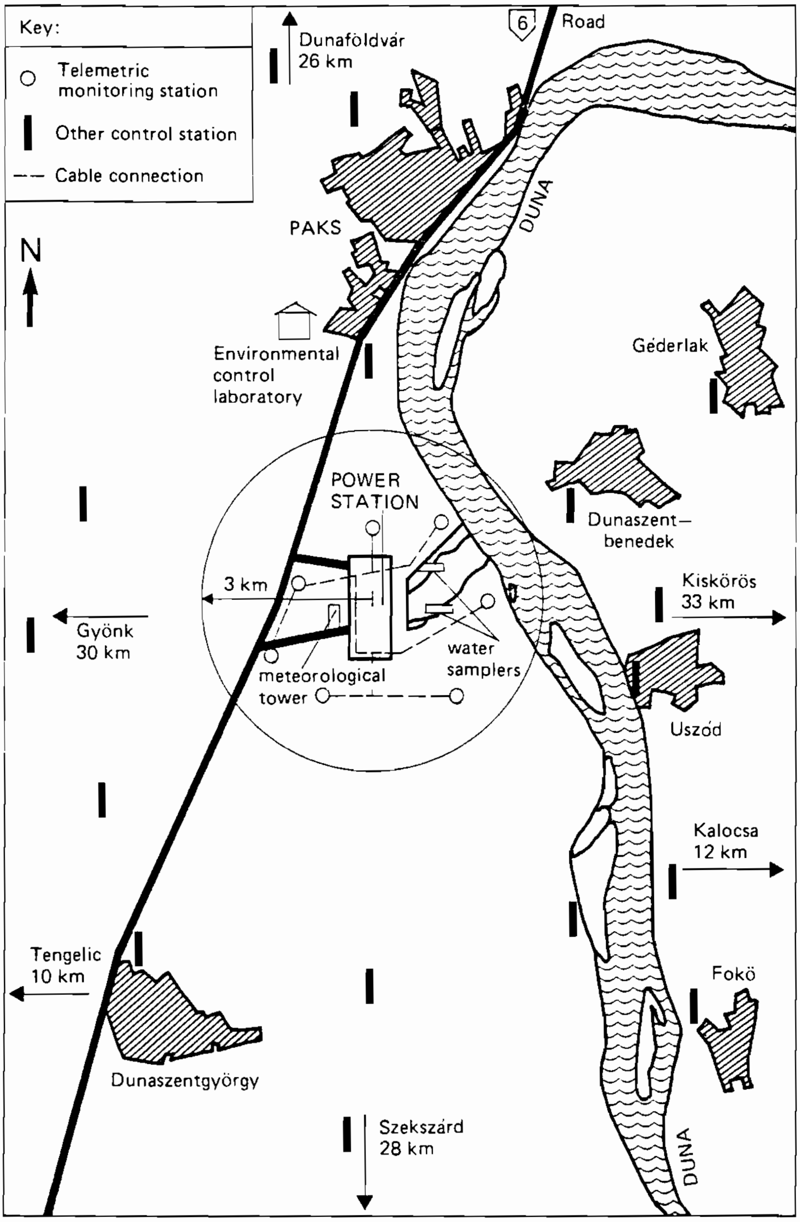

Figure 1. The location of the Paks nuclear power station and its off-site monitoring points.

THE FEATURES OF A MAXIMUM CREDIBLE ACCIDENT AT THE STATION

The plans for off-site radiation monitoring were developed for the case of a MCA in a pressurized water reactor of the type WWER-440. An MCA in this type of reactor, with a wet condenser system, could take the following form.

Event: both-end rupture in the main coolant pipe with a nominal diameter of 500 mm (design basis accident).

— *Volume of expansion space:* 30,000 m^3
— *Maximum pressure in expansion space:* 240 kN/m^2
— *Maximum time of overpressure in expansion space:* 12 min
— *Significant radioactive materials released during period of overpressure:* see Table 1
— *Possible release height:* 0 to 40 m
— *Hypothetical release height:* 15 m
— *Assumed Pasquill diffusion category:* F
— *Assumed wind velocity:* 2 m/s
— *Maximum dose vs distance from the release point:* see Figure 2.

Table 1. Possible releases of radioactive materials in the case of a maximum credible accident at a pressurized water nuclear reactor.

Group	Isotope	Half-life	Release (Curies)
Iodine	^{131}I	8 d	1,200
	^{132}I	2 hr	300
	^{133}I	20 hr	1,200
	^{135}I	7 hr	700
Noble gases	^{85}Kr	10 yr	150
	^{133}Xe	5 d	2,800

The calculations of maximum dose and relative dose distribution are based on the amount of released radioactive materials and on weather conditions. As can be seen in Figure 2, in the case of the Paks station the dose to the thyroid through iodine inhalation is the most significant short-term dose. Ingestion doses have not been taken into account because the accident management team can prevent that type of dose quite easily.

A special zone that has a low population density and practically no children surrounds the power station. Therefore the thyroid doses for children (indicated by curve (1) in Figure 1) are given only for distances greater than 3 km. Whole body doses from beta and gamma radiation are negligible in comparison with the thyroid doses.

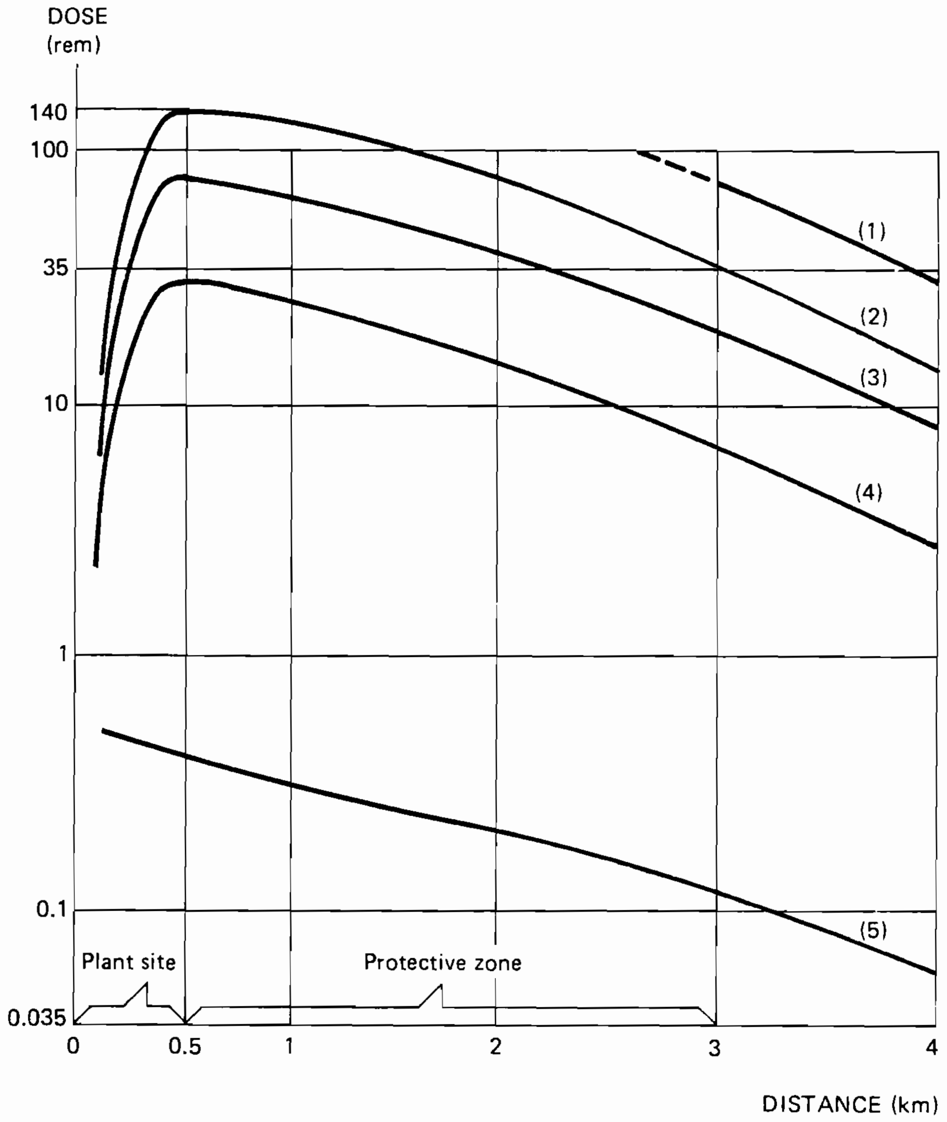

Figure 2. Maximum dose vs distance from the plant in the event of a maximum credible accident (MCA). Curve (1) shows the iodine inhalation thyroid dose for children; curve (2) shows the iodine inhalation thyroid dose for adults; curve (3) shows the iodine inhalation thyroid dose for adults, assuming intake of iodine tablets within 2 hours after inhalation; curve (4) shows the iodine inhalation thyroid dose for adults, assuming intake of iodine tablets within 6 hours after inhalation. Curve (5) shows whole body beta and gamma doses.

The dose effect of inhaled iodine can be reduced by medical countermeasures, i.e., by intake of iodine tablets. The dose effect can be reduced by a factor of 5 if the intake of tablets can be arranged within two hours; it can be reduced by a factor of 2 if intake occurs within 6 hours of inhalation.

PRINCIPLES OF DOSIMETRY

Before countermeasures are taken in the case of an accident, the target population group must be specified and the required measures must be determined. The time sequence of decision-making activities in the event of an accident is shown in Figure 3. Before decisions about countermeasures can be made, it is necessary to estimate the probable maximum doses in the absence of countermeasures and the territorial distribution of these doses. The results of cost-benefit analyses of each countermeasure alternative should be inputs to the decision-making process.

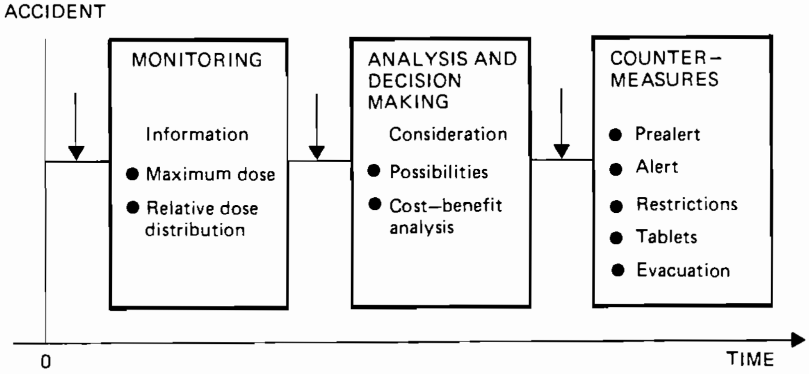

Figure 3. The time sequence of actions that should be taken in the event of a maximum credible accident (MCA) at a nuclear power plant. The arrows indicate requirements for telecommunications.

During normal operation, when there is underpressure in the hermetic expansion space, radioactive releases into the atmosphere can be measured by the stack monitoring system. This is not possible in the case of a MCA, because the release would involve leakage in the expansion space walls. In such a situation involving overpressure in the expansion space, the only way to determine off-site doses is to measure the actual dose distribution in the environs of the station. The collection of meteorological data for use in atmospheric diffusion calculations is very important, for the calculations yield an extrapolated dose distribution for points that cannot be measured directly.

As shown in Table 2, there are several methods for measuring probable iodine inhalation doses. The best method is the continu-

Table 2. Quality of information provided by various methods for measuring probable iodine inhalation doses.

Method	Quality of information provided: Maximum dose	Quality of information provided: Relative dose distribution	Time required (hours)
Measurement of wind direction and velocity.	None	Poor	0.1
Analysis of wind data and Pasquill category.	None	Moderate	0.2
Meteorological measurements and surface contamination measurement after the accident.	Poor	Moderate	1-3
Meteorological measurements and continuous air sampling during the accident.	Moderate	Moderate	1-3
Meteorological measurements and iodine telemetry.	Moderate	Moderate	0.2-0.4
Meteorological measurements and use of the iodine and gamma dose telemetric system.	Good	Good	0.2-0.4

ous measurement of the time integrated radioiodine concentration. The continuous-operation wide-range telemetric iodine monitor provides the most rapid and reliable means for calculating probable iodine inhalation doses. If the measuring points are at appropriate locations, from the point of view of population density, this instrument provides a considerable portion of the monitoring data needed for decision making in the event of an accident at a nuclear reactor.

Using the cross-wind iodine distribution calculated for actual weather conditions (in terms of wind data and Pasquill categories), it is possible to estimate the maximum dose and the dose distribution between the monitoring points, as shown in Figure 4. But this extrapolation may be inadequate for high stability categories (Pasquill categories E and F). One possible way to increase the accuracy of extrapolation is to use more monitors; however, the cost of a large number of such monitors would be very high. Also, for a given stability category, the

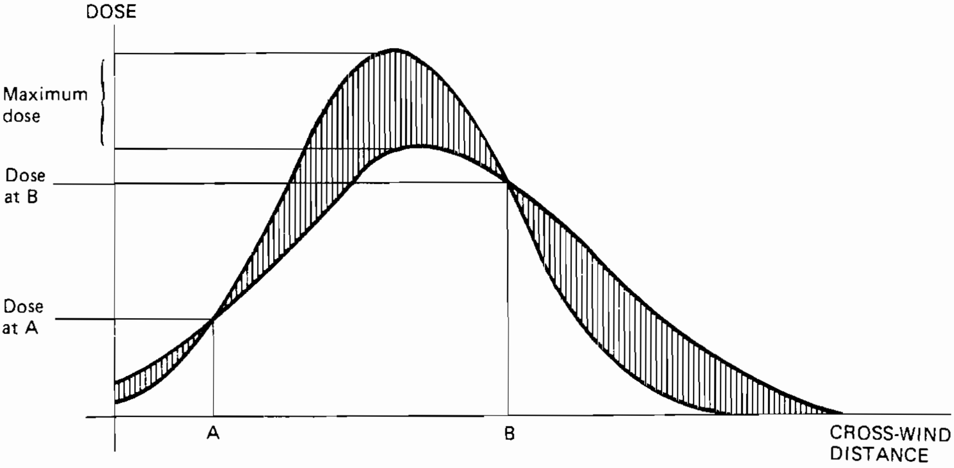

Figure 4. The cross-wind distribution of calculated iodine doses under maximum credible accident (MCA) weather conditions fitted to measured values at points A and B. The shaded area indicates possible uncertainty in dose values.

intensity of gamma radiation has a broader distribution than does iodine (see Figure 5). Therefore parallel measurement of the integrated iodine concentration and the gamma dose at the same points can decrease the cost and improve the accuracy of the accident dosimetry monitoring system.

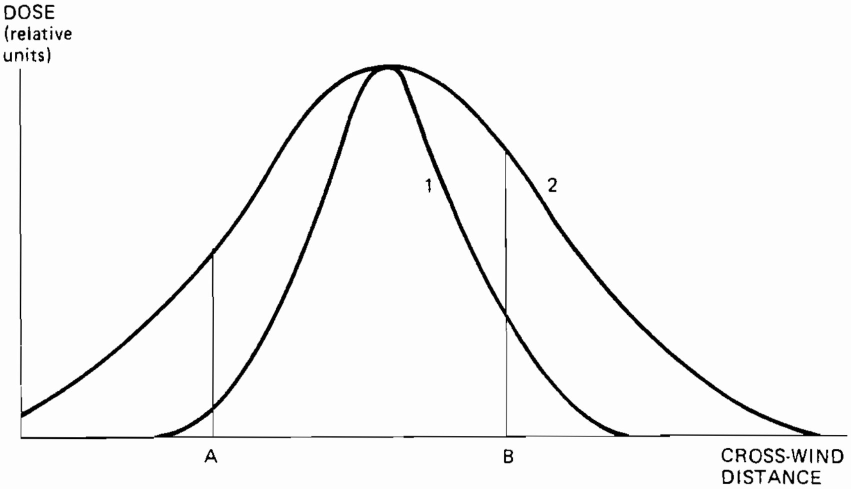

Figure 5. Iodine (curve 1) and gamma dose (curve 2) distributions under maximum credible accident (MCA) meteorological conditions.

Table 3. Main components of the off-site monitoring system serving the Paks nuclear power station.

Component	Used in the case of normal releases	Used in the case of accidental releases
Release measuring system (stack monitor)	+	
Meteorological tower (120 m high)	+	+
Telemetry system	Gamma radiation only	+
Other control stations (tacky cloth collectors, thermoluminescent dosimeters (TLDs))	+	+
Other samples	+	+
Mobile on-site gamma-spectrometry equipment	+	
Roving car (which records dose-intensity and contamination, reads TLDs, and assesses tacky cloth collectors)		+

The choice of the distance of the monitoring stations from the plant involves two conflicting requirements: if the distance is small fewer monitors are required to achieve a given accuracy of the cross-sectional extrapolation; this implies less accuracy for larger downwind distances. Conversely, if the distance is large, more monitors are needed to achieve a given level of accuracy, but greater accuracy is possible at large downwind distances. Generally the optimum distance seems to be from 1 to 3 km, but this depends very much on the local situation and requirements.

The collection of dosimetric and meteorological data by means of a telemetric system, as described above, makes it possible to estimate the maximum dose and relative dose distribution in a very short time—about half an hour. This information then may become a basis for decision making concerning countermeasures by responsible authorities at the scene of a nuclear accident.

The accident dosimetric monitoring system at the Paks nuclear power station is based on the telemetric iodine and gamma monitoring system described above. Table 3 provides additional information on the most important components of the system, and their use in the case of normal and accidental releases.

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MAIN RESULTS OF THE GERMAN NUCLEAR POWER PLANT RISK STUDY

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INTRODUCTION

When a utility files an application for the construction and operation of a nuclear power plant, the responsible authorities have to examine whether the necessary precautions have been taken, in accordance with the state of the art, to prevent any damage that may result from the construction and operation of the plant. This includes the demonstration that operational discharges of radioactive effluents will be kept as low as possible, even if they are already below the acceptable limits, and that accidental releases will be limited in such a way that neither personal injuries nor property damage are likely.

These precautions against damage require comprehensive accident analyses. In such analyses, it must be demonstrated that a plant's safety features are capable of coping with possible accidents. For this purpose, plant design is based on the greatest loads. A simultaneous failure of the redundant safety features is considered to be so unlikely that it is not taken into account in the design.

Nevertheless, and irrespective of the individual nuclear licensing procedures, attempts have been made to estimate the consequences of extremely unlikely accidents such as might result from the failure of safety features. However, these analyses covered only one aspect of the risk of reactor accidents. Another aspect is the *probability* of such accidents, since risk includes both the extent of damage and its probability.

The US Reactor Safety Study (USAEC 1975), the so-called Rasmussen Report, was the first comprehensive risk study to consider both the scale of damage associated with nuclear accidents, and the probability of such accidents. The study consisted of a systematic investigation of the accident risk posed by two typical US nuclear power plants (a boiling water and a pressurized water reactor) and an extrapolation of the results to the total number of plants in the country.

PURPOSE AND TASK OF THE GERMAN RISK STUDY

Immediately upon publication of the Rasmussen Report, its results were studied with great interest by other countries engaged in the peaceful use of atomic energy. The question was raised as to how far the results may be applicable to the conditions prevailing in other countries. Although, in principle, the Federal Republic of Germany (FRG) and the US use the same type of reactor, i.e., the light-water reactor, there are important differences:

- As far as engineered features are concerned, the US reference plants differ from German plants in several ways. Differences in design and function of the safety features are of major significance for a risk assessment.
- The population density in the Federal Republic of Germany is far greater than in the US. The density is about 3 times greater in the vicinity of nuclear power plants. Overall the density is about 11 times greater.

Both factors are of great importance in the determination of risk and require separate investigations for quantification purposes. About six months after the publication of the Rasmussen Report, the Federal Minister of Research and Technology awarded a contract for a German study, as part of the Reactor Safety Research Program. The Cologne-based Gesellschaft für Reaktorsicherheit (GRS) was the main contractor, and Prof. Adolf Birkhofer, one of its Executive Directors, was entrusted with the scientific management of the project. GRS prepared the event tree and failure tree analyses for the accidents, as well as the descriptions of core meltdown accidents and the determinations of radioactive releases.

Other institutions entrusted with important tasks included Kernforschungszentrum Karlsruhe (which prepared the accident consequence model and carried out the accident consequence calculations); Institut für Unfallforschung des Technischer Überwachungs-Verein Rheinland in Cologne (which contributed to the emergency response model), and the Gesellschaft für Strahlen- und Umweltforschung at Neuherberg near Munich (which established the dose-response and dose-risk relationships).

The objectives of the German Risk Study may be summarized as follows:

- To determine the risk posed by accidents at nuclear power plants for the German population.
- To help identify important areas for future research and development projects in the field of reactor safety.

In addition, the Study offered an opportunity for testing the applicability of probabilistic methods for safety evaluation.

Biblis B, a representative, operational 1300 MW pressurized water reactor (PWR) plant served as a reference plant for investigations of engineered plant features. For risk evaluation purposes, all nuclear power plant sites in the FRG with light-water reactors of 600 MW or more in operation, under construction, or in the licensing process on July 1, 1977 were considered.

To meet these far-reaching objectives, the German Risk Study was subdivided into two major phases. *Phase A* used a great number of the basic assumptions and methods contained in the Rasmussen Report. *Phase B*, which is intended primarily for vigorous special investigations, takes into account to a greater extent new methodological developments and recent results of reactor safety research. The Federal Government desires the cooperation of additional institutions and groups in Phase B.

APPROACH

The different steps of the investigations carried out within the framework of the German Risk Study are depicted in Figure 1. The first step was to identify initiating events that may lead to radioactive releases to the environment. Different event trees emerge from this exercise, depending on whether the required safety systems are available or not. Event tree diagrams were drawn to provide greater clarification. The separate trees involve different probabilities, which depend on the frequency of occurrence of the initiating events and the availability of safety features.

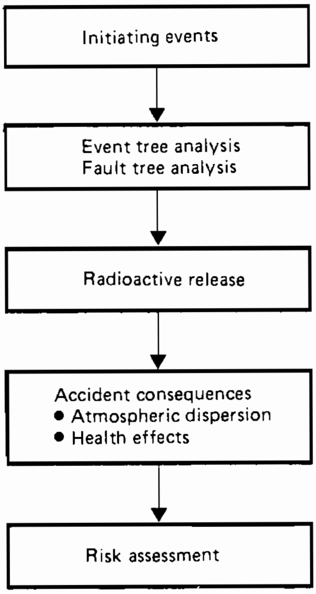


Figure 1. Topics of analysis in the German Risk Study.

The necessary reliability analyses were carried out with the aid of failure trees.

Subsequent investigations focused on the processes involved in the meltdown of the reactor core, the behavior of the molten core, the behavior of the containment and its possible failure modes, the transport of radioactivity inside the containment, and finally releases of radioactivity to the environment. The study group considered the dynamic processes inside the containment and determined the probabilities of the various failure modes.

The space-dependent and time-dependent radioactive concentrations in the environment of the plant were calculated, taking into account the weather-dependent dispersion of the radioactive plume, and were used to determine individual doses. Based on emergency operational responses that would occur as a function of these exposures, reduced doses and the associated health effects to be expected as consequences of the accident were determined. Risk statements could then be presented based on the numbers of fatalities and associated frequencies.

RESULTS OF INVESTIGATIONS

Analyses of Engineered Plant Features

The investigation covered some 100 accident sequences that can lead to radioactive releases. Table 1 shows the initiating events that may lead to a core meltdown, their probabilities, and the data for the associated probability of a failure of the required system function. The frequency of core meltdown accidents was determined to be about 1 in 10,000 per year.

The relative contributions of the various failure modes to the initiation of a core meltdown are shown in Figure 2. The greatest contribution to the core meltdown frequency is made by a small break in a reactor coolant pipe when this is not countered by the safety systems. There are two main reasons for this. On the one hand, the frequency of a small break is relatively great, and on the other hand, coping with such breaks requires substantial manual interventions, which have a relatively high failure rate. The second most important initiating event is the loss of offsite power—but this ranks far behind the small pipe break. Large pipe breaks play a subordinate role. In all, two-thirds of the total frequency of core meltdowns are caused by human errors (see Figure 3). Table 2 provides a survey of the release categories that have been investigated and the associated release frequencies (which are not identical with the core meltdown frequencies).

Determination of Accident Consequences

The determination of *potential radiation doses* was the first step in the calculation of accident consequences. Concentrations of radioactive materials in the air and on the ground were cal-

Table 1. Summary results of the event tree analysis.

Accident initiating event	Probability of occurrence of the initiating event per reactor year P_1	Probability of failure of required safety functions P_2	Probability of occurrence of core melt per reactor year $P_3 = P_1 \cdot P_2$
Large LOCA	$2.7 \cdot 10^{-4}$	$1.7 \cdot 10^{-3}$	$5 \cdot 10^{-7}$
Medium LOCA	$8 \cdot 10^{-4}$	$2.3 \cdot 10^{-3}$	$2 \cdot 10^{-6}$
Small LOCA	$2.7 \cdot 10^{-3}$	$2.1 \cdot 10^{-2}$	$5.7 \cdot 10^{-5}$
Loss of off-site power (emergency power case)	$1 \cdot 10^{-1}$	$1.3 \cdot 10^{-4}$	$1.3 \cdot 10^{-5}$
Loss of main feedwater supply	$8 \cdot 10^{-1}$	$4 \cdot 10^{-6}$	$3 \cdot 10^{-6}$
Emergency power case with small leak at pressurizer	$2.7 \cdot 10^{-4}$	$2.6 \cdot 10^{-2}$	$7 \cdot 10^{-6}$
Other transients with small leak at pressurizer	$1 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-6}$
ATWS events[a]	$3 \cdot 10^{-5}$	$3 \cdot 10^{-2}$	$1 \cdot 10^{-6}$

[a] Anticipated Transients Without Scram

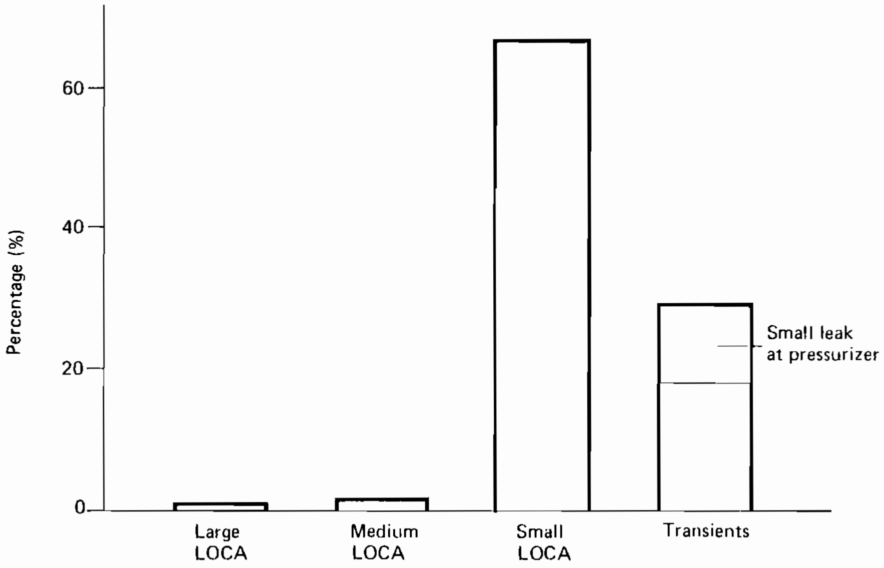


Figure 2. The relative contribution of various accident-initiating events to the probability of a core meltdown.

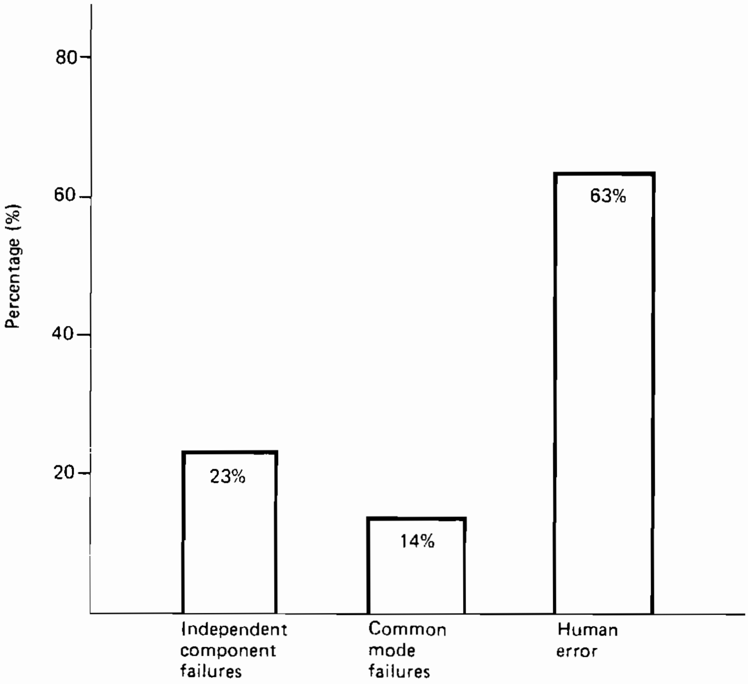


Figure 3. The relative contribution of various failure modes to the probability of a core meltdown.

Table 2. Times of release and probabilities of release by release category.

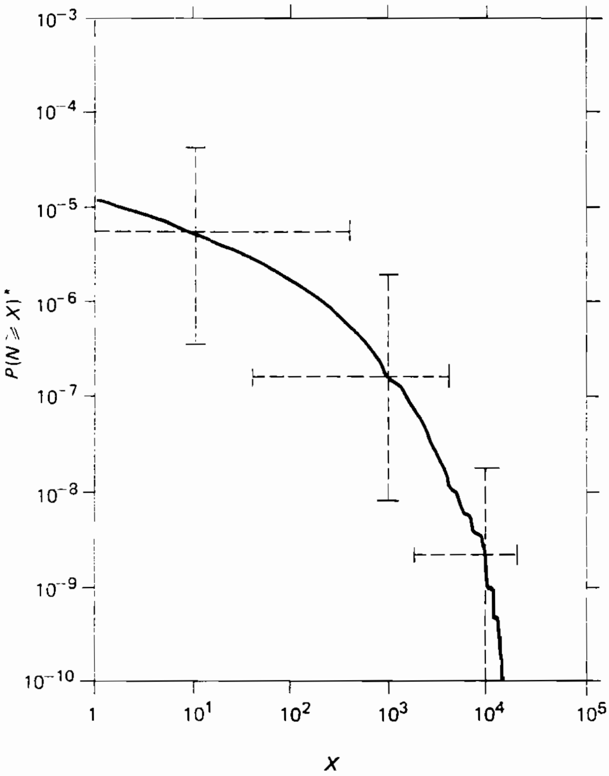
Release category	Description	Time of release (hr after accident)	Probability per reactor year[b] (mean)
1	Core melt, steam explosion	1	$2 \cdot 10^{-6}$
2	Core melt, large containment leak (300 mm diameter)	1	$6 \cdot 10^{-7}$
3	Core melt, medium containment leak (80 mm diameter)	2	$6 \cdot 10^{-7}$
4	Core melt, small containment leak (25 mm diameter), late containment overpressure failure	2	$3 \cdot 10^{-6}$
5	Core melt, late containment overpressure failure, failure of filter systems	25	$2 \cdot 10^{-5}$
6	Core melt, late containment overpressure failure	25	$7 \cdot 10^{-5}$
7[a]	Design basis accident, large containment leak (300 mm diameter)	0	$1 \cdot 10^{-4}$
8[a]	Design basis accident	0	$1 \cdot 10^{-3}$

[a] Release categories 7 and 8 are not core meltdown accidents.

[b] The probabilities include 10% contributions from adjacent release categories.

culated, and these doses supplied the criteria for establishing necessary protective actions and countermeasures. The *expected doses* were then calculated, based on the assumed implementation of dose-reducing measures.

With the aid of a sinusoidal dose-response relationship for early fatalities (threshold value: 100 rad; LD_{50}: 510 rad; LD_{99}: 770 rad), and a linear dose-response relationship for late somatic effects (risk factor of approximately 10^{-4}/rem), the expected doses were then used to calculate early and late fatalities. In addition, the genetically significant collective doses were determined. Figure 4 shows the cumulative frequency distribution of early fatalities per year for 25 plants, and Figure 5 shows the distribution of late fatalities. The dashed lines indicate 90% confidence limits. The maximum number of collective fatalities as calculated in the course of the study is 14,500 early deaths and 104,000 late deaths. The two figures belong to different accident sequences. For both events, the frequency of occurrence is 1 in 2,000,000,000 per year. The associated accident sequences

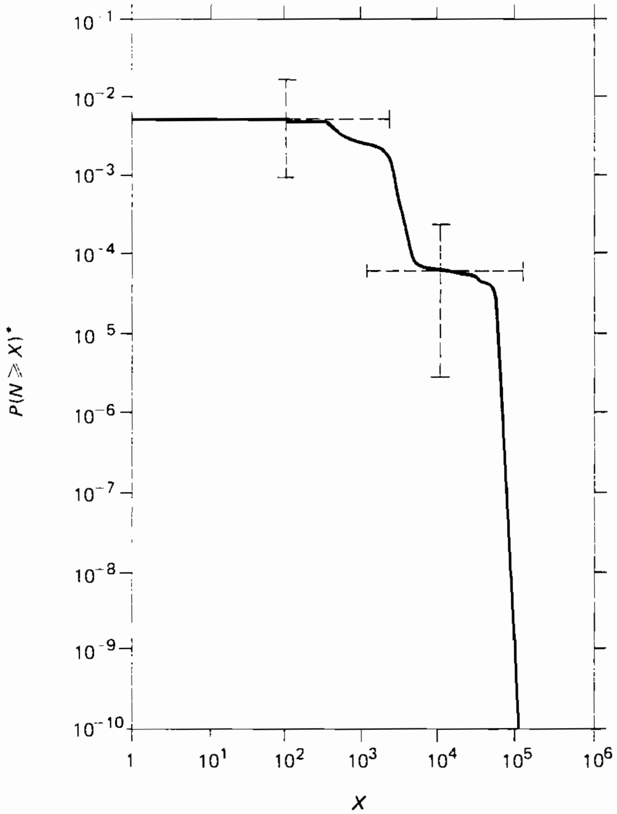


*Probability per year that N, number of early fatalities, $\geq X$

Figure 4. Plot showing the complementary cumulative distribution function for early fatalities per year for 25 plants. The dashed lines indicate 90% confidence limits.

represent a combination of the most adverse release conditions, weather conditions, and population distributions.

The number of late fatalities as calculated in the study is relatively great. Even for events with a probability of 1 in 100,000 per year, 54,000 late deaths were calculated. On the one hand, this is due to the fact that late fatalities were calculated on the basis of a linear dose-response relationship *without* a threshold value, i.e., in the conservative approach taken it was assumed that late somatic effects will be caused by *any* dose. On the other hand—apart from very serious accidents, which are characterized by an early containment failure and great radioactive releases—the overwhelming percentage of late fatalities was determined to be caused by specific weather conditions; these conditions affect relatively large areas, and, after large releases, lead to concentrations below the action levels for the introduction of countermeasures.



*Probability per year that N, number of late fatalities, ⩾ X

Figure 5. Plot showing the complementary cumulative distribution function for late fatalities per year for 25 plants. The dashed lines indicate 90% confidence limits.

THE EMERGENCY RESPONSE MODEL

In the emergency operational response model employed in the German Risk Study, the spatial distributions of dose rates in the open air, i.e., the so-called potential doses, were calculated first. For cases in which doses exceeded the given reference limits, selected isodose lines were used to delimit areas in which different measures would be implemented.

The model contains 5 areas (B_1, B_2, C, D_1, and D_2) determined using a dose-dependent approach. Area A, which covers the immediate vicinity of the plant, was defined to be independent of any dose and thus to be of constant size. The rigid delineation of this area is due to the occurrence of high doses and the fact that large releases of radioactivity and unfavorable dispersion conditions make it impossible to carry out and evaluate radioactivity and dose rate measurements. The area is shaped like a keyhole and consists of a 30° sector with a depth of 8 km in the direction of the dispersion of the radioactive plume, and a full circle with a radius of 2.4 km, i.e., a total area of 33 km^2. The inclusion of a full circle is necessary, for turbulence and diffusion may spread radioactivity in all directions over limited distances and direct radiation from the plume is also emitted in all directions over limited distances. The study group postulated that emergency preparedness and evacuation plans exist for Area A.

Following the establishment of the areas, doses were again calculated, taking into account the protective actions and countermeasures, and fatalities were determined on this basis. The number of early fatalities depends on bone marrow doses, while late fatalities depend on whole-body doses. The isodose lines delimiting the areas refer either to the potential whole-body dose or to the potential bone marrow dose. The boundaries of the areas were set so that early fatalities would only occur in Areas A, B_1, and B_2. Figure 6 shows the subdivision of emergency response areas used in the study.

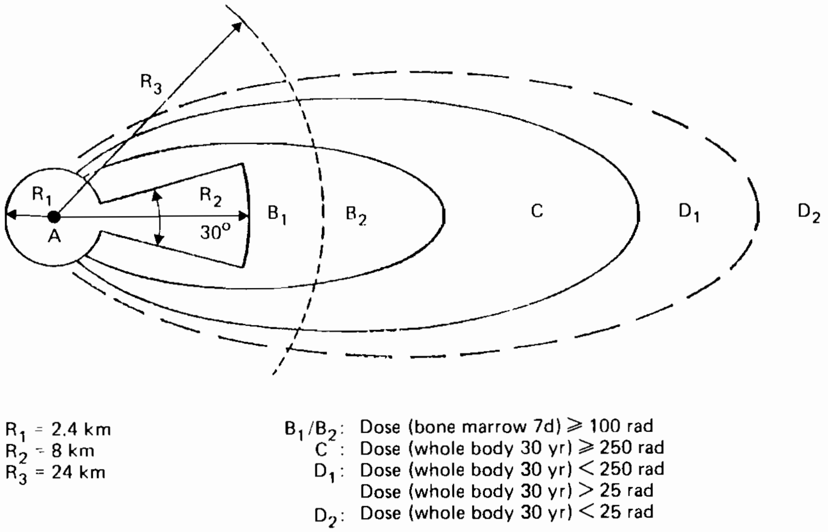


Figure 6. The risk areas used in the German Risk Study.

PROTECTIVE ACTIONS AND COUNTERMEASURES

The following protective actions and countermeasures were considered in the study:

- Taking shelter in houses;
- Evacuation;
- Rapid relocation;

- Relocation;
- Decontamination; and
- Temporary prohibition of the consumption of local agricultural products.

Table 3 shows the apportionment of protective actions and countermeasures by area and their time schedule in the German Risk Study.

Table 3. Emergency measures by risk area and time following the accident.

Risk area	Time after accident	Emergency measure
A	2 hr 2-12 hr	Shelter Evacuation
B_1	2 hr 14 hr	Shelter Fast relocation
B_2	— 14 hr	No shelter Fast relocation
C	— > 30 days	No shelter Relocation ($5\ km^2$/day)
D_1	30 days	Decontamination [Dose (30 years) < 25 rad after decontamination]
D_2	—	—

The Initial Protective Action Phase

An initial phase of 2 hours was postulated for initiating actions (informing official decision makers, meeting staffs, sounding of alerts, informing the population, etc.). The standard emergency signal would be used to warn the population; in the FRG this is the one-minute howling sound of a siren. Loudspeaker vans are used in Area A and, if appropriate, in Area B_1 to ask the population to take shelter in buildings and switch on radio or television sets. It was assumed that 3% of the population would ignore the warning and remain in the open. In cases where radioactivity reaches certain parts of the areas within 2 hours after the beginning of the accident, a mixed distribution of the population in large and small buildings and in the open was assumed and an averaged shielding factor was used.

Emergency Operational Response Measures in Area A

The aim of emergency operational response measures for Area A was to prevent or limit acute injury to persons. As a consequence of German licensing practices, Area A will generally be rural. It was assumed that after 2 hours 65% of the population would have retreated into larger buildings or the cellars of small buildings, and 32% would be in smaller buildings but not in cellars. The 3% who would stay out in the open during the initial phase were assumed not to retreat into houses later.

The protective effect of buildings consists of lowered exposure (as compared with the open air) to ionizing radiation from the air or from the ground, since distances to the radioactive materials are greater; the brickwork, and—in the case of cellars—the ground, also act as shields. The following protective factor was defined for the dose-reducing effect of buildings:

$$\text{Protective Factor} = \frac{\text{Dose outside the building}}{\text{Dose inside the building}}$$

The protective factor associated with protected places in larger buildings or in cellars of smaller buildings was assumed to be 10 for ground radiation, and 6.7 for plume radiation. The protective factor associated with protected places other than cellars in smaller buildings was assumed to be 5 for ground radiation and 3.3 for plume radiation.

In Area A the highest dose rates are reached in almost any kind of weather, and there is no time to carry out and evaluate measurements. This is why it was postulated that the emergency control staff would order an evacuation in any case.

The study group considered two parameters with respect to the time needed for evacuation: the time until people begin to drive away in their own cars or in other transport vehicles, and the time until they leave the danger zone. It was assumed (conservatively) that the maximum value of the first parameter will be 12 hours, i.e., that the inhabitants will begin their trips between 2 and 14 hours after the beginning of the accident. In all cases it was assumed that the travel time to the boundaries of the danger zone is 1.5 hours. The travel period was considered to be an unshielded stay in the open, involving the same local dose rate as at the place of residence. Because of the direction of evacuation (which will be a combination of the directions 'away from the plant' and 'out of the danger zone'), this will generally correspond to the highest dose rate.

The return of the population is scheduled for the time when radioactive decay, weather conditions, and decontamination measures have reduced the existing ground contamination to a level such that the resulting potential whole-body dose over a period of 30 years will not exceed 25 rad. This accumulated dose is approximately 7.6 times the dose originating from natural background radiation. Residual contamination may cause late fatalities among both persons now living and those born after the accident.

The measures taken in Area A will affect an average of 6,800 persons (206 inhabitants/km^2). In the most unfavorable case, they will affect 42,000 persons (1,270 inhabitants/km^2).

Emergency Operational Response Measures in Areas B_1 and B_2

According to the calculations carried out in the course of the German Risk Study, the necessary emergency response measures will remain restricted to Area A in the majority of all accidents involving radioactive releases. Larger areas will be affected only in 3 (out of a total of 8) release categories and in only about 1% of all core meltdown accidents. To handle these cases, the study group defined Area B; it envelops the 30° sector of Area A in the direction of dispersion, and is limited by a potential 100 rad isodose line for a bone marrow dose resulting from ground radiation accumulated over 7 days. Area B_1 extends 24 km in the direction of dispersion. Just as for Area A, it was postulated that the population of Area B_1 will be asked to take shelter inside houses.

The study group chose the term 'rapid relocation' to describe the subsequent movement of the population out of Area B_1. Taking a conservative approach, it was assumed that no preparation exists for such an action. For this reason the rapid relocation phase was assumed to begin 14 hours after the occurrence of the accident at the earliest, i.e., only when evacuation of Area A was complete.

To calculate overall doses it is necessary to know the duration of travel during rapid relocation. The study group defined three different types of areas for this purpose: urban, average population density, and rural. A computer code for the simulation of population movements was used to determine a traveling time spectrum for each type of area. The spectra were approximated in such a way that a given traveling time was allocated to one-third of the population of each type of area. As in the case of Area A, travel periods in Area B_1 were considered to be unprotected stays in the open. Added to the traveling times was a uniform preparatory time of 0.25 hr with unshielded ground radiation. To determine the time of the return of the population, the same limit for accumulated potential whole-body dose from ground radiation (25 rad over 30 years) was used as in Area A. The subsequent late fatalities to be expected were also taken into consideration.

For 2 release categories it was calculated that the 100 rad isodose line will extend more than 24 km from the plant in the direction of dispersion, under 4% or 10% of weather conditions (depending on the release category). This area, beyond the 24 km mark, was termed B_2 in the study. No emergency preparedness measures exist for this area in any case. To be on the safe side, the study group assumed that the inhabitants in Area B_2 would pursue their normal activities until the beginning of the rapid relocation phase. Both rapid relocation and return to Area B_2 were treated as for Area B_1. The mean size and maximum size of Areas B_1 and B_2 were calculated to be 14 km^2 and 379 km^2, respectively. The average number of persons affected would be 4000 (226 inhabitants/km^2). In the most unfavorable case the number would increase to about 1 million (2600 inhabitants/km^2).

Emergency Operational Response Measures in Area C

According to the calculations of the Risk Study, no doses involving early fatalities will be reached beyond Area B_2. However, areas were determined that could not be decontaminated sufficiently, with respect to almost all release categories. Thus, a temporary relocation of the population to reduce late fatalities was also considered in the model. Area C was defined to envelop Areas B_1 and B_2. Area C is limited by a 250 rad isodose line for the potential whole-body dose, which would result from the accumulation of external ground radiation over 30 years.

It was also postulated that a long-term stay of persons in this area would only be acceptable if the potential whole-body dose has been reduced to 25 rad. For cases that necessitate the demarcation of Area C, the study group postulated a relocation beginning after 30 days. Relocation begins in the subareas closest to the plant and then extends to greater distances. The doses received until termination of the relocation measure were estimated assuming a mixed distribution of the population in large buildings, small buildings, and in the open air, along with the associated shielding factors.

The study group assumed that decontamination would be carried out only if, or not until, the decontamination factor

$$DF = \frac{\text{Radioactivity before decontamination}}{\text{Radioactivity after decontamination}}$$

—which is needed to arrive at 25 rad for the potential whole-body dose resulting from ground radiation and accumulated over 30 years—is smaller than 10. Thus decontamination activities are carried out as soon as the potential dose caused by ground radiation falls below 250 rad in subareas of Area C as a result of radioactive decay and weather-related effects.

After the limit of 25 rad is reached in 30 years, the population will return. The collective dose is calculated as before, on the basis of the dose received during the periods before relocation and after return. Late fatalities to be expected from residual contamination, including fatalities of persons born after the accident, are also calculated for Area C.

According to model calculations, the mean size and maximum size of Area C are 11 km^2 and 5700 km^2, respectively. Thus, the mean number of persons concerned is about 2900 (260 inhabitants/km^2); in the most unfavorable case this number will increase to about 2.9 million (510 inhabitants/km^2). Large areas and great numbers of persons were involved only where the dispersion of radioactive material extends into densely populated regions during rainy weather conditions. The fact that in densely populated urban areas a great deal of radioactive material will flow into the sewers with the rainwater was not taken into account.

Emergency Operational Response Measures in Areas D_1 and D_2

If the potential whole-body dose accumulated over 30 years as a result of ground radiation is between 250 and 25 rad, this value can be reduced to less than 25 rad in all areas by means of a decontamination factor $\leqq 10$. For this reason the study group defined Area D_1, which envelops Area C and is limited by the whole-body ground-radiation 30-year isodose line of 25 rad. It was assumed that no population movements occur here and that the inhabitants pursue their normal activities at all times. Decontamination activities were postulated to go into effect in all of Area D_1 after only 30 days. The late fatalities to be expected because of this delay and the remaining residual contamination, were taken into account.

The area surrounding Area D_1 was termed D_2. This area was defined in accordance with the fact that the potential whole-body dose resulting from ground radiation and accumulated over 30 years is below 25 rad. The only measure that was considered involves restrictions in the consumption of local agricultural products. For this area, expected late fatalities were also taken into account.

EVALUATION

In spite of differing engineered plant features and differing site conditions, the results of the German Risk Study are similar to those of the Rasmussen Study. Considering the present state of the art, however, the inherent significance of every risk analysis is restricted. Due to the existing uncertainties, it is not possible to provide precise risk calculations, but rather only risk assessments.

The dependence of the German Risk Study on models becomes clear in the investigation of event sequences associated with radioactive releases. Models were used that describe core meltdown, radioactivity release, dispersion, and biological radiation effects. The lack of detailed knowledge was compensated by simplifying and pessimistic assumptions, so as to cover the most unfavorable case.

The accident sequence calculations carried out in the study permit refined evaluation of the different accident parameters that can decisively affect the scale of accident-related damage. The knowledge that was acquired from the calculations can be used for future emergency planning and preparedness programs.

The study provides an idea of the period of time during which operational response is necessary and possible.

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23

NOISE DIAGNOSIS - A METHOD FOR EARLY DETECTION OF FAILURES IN A NUCLEAR PLANT

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During the past several years a large number of possible failures in nuclear plants have been analyzed. As a result of these investigations, new safety concepts have been developed and implemented in nuclear plants—frequently without consideration of their costs. There is a need for such investigations to pay more attention to methods for early detection of malfunctions; such methods include computerized data processing and evaluation. Until now failure analysis has had the character of a postmortem procedure: in the framework of a given cause—consequence model, a computer generally calculates the set of all causes $\{u\} = U$ of a perturbation that has occurred in a plant at time t_s. This operation is shown schematically in part (a) of Figure 1. If the control process for the detection of failures is implemented earlier in the time scale, at time t_a rather than t_s, to detect an incipient failure, then we may speak of early perception of malfunctions. This method involves the quasi-simultaneous calculation of the possible set of consequences $\{f\} = F$ associated with the perturbation. This is shown in part (b) of Figure 1.

Noise diagnosis constitutes one method for early detection of plant failures. The method is based on the fact that nearly all undesired processes in a nuclear power plant make a measurable contribution to the noise portion of signals. Well-known examples of undesired processes in pressurized water reactors include core-barrel movement, the vibration of control elements, the appearance of loose parts in the coolant flow, and the process of coolant boiling. Each of these processes has been implicated in past nuclear plant failures.

In the German Democratic Republic (GDR) P. Liewers and his colleagues have introduced noise analysis systems into the primary circuit of WWER-440 pressurized water reactors (PWR) (Buttler *et al.* 1977). The most progressive version (RAS-II) has become a prototype for research and routine investigations. This diagnostic system allows the analysis of signals from about 120 detectors. Half of these are neutron flux detectors in in-core and ex-core positions within the reactor. In addition, piezoelectric detectors around the vessel measure accelerations and pressure fluctuations; for instance, accelerations at the top of the control rods are measured. The diagnostic system also includes the use of piezoelectric detectors to observe the main circulation pumps.

Of course the diagnostic system involves much more than delivering a set of signals. Conventional measuring techniques take only momentary averages into account; the noise portion (i.e., signal fluctuations in relation to the momentary averages, within the limits of error) is not considered. The diagnostic system under discussion here extracts useful information from noise signals.

Figure 2 shows a scheme for the evaluation of noise signals. Noise information from the different detectors with their preamplifiers is transferred by cable to the central main amplifiers for final signal conditioning. Programming units make it possible to observe signals or a combination of signals and to test them acoustically or visually in a display. The signals can be evaluated with and without frequency limitations; they can also be recorded on magnetic tape or transmitted to a process computer for further analysis.

Well-known correlation methods, especially the spectral power density concept, are used to analyze noise signals. Assumptions about the transfer function of the process under consideration have to be introduced to evaluate the signal spectra model. Parameters of the process can be investigated by fitting estimated spectra to this mathematical model.

In the course of using the noise diagnosis system, two shortcomings of its operation within a control system have become evident. First, a specialist must be present to interpret the noise information. Second, the advantage of detecting suspicious situations early is partly lost because noise analysis is performed off-line. Investigations have now been started for monitoring selected disturbances to quickly provide initial information to the operator.

The utility of noise diagnosis may be demonstrated by the following example. The control elements of our PWRs are capable of oscillating like a pendulum (Hennig and Grunwald 1978). Therefore neutron noise is composed of space-dependent contributions from all moving elements. Through the application of a special correlation technique to signals from the installed noise instrumentation, it is possible to separate out the neutron noise that is correlated with the movement of the control elements under consideration. This is possible even when all the elements are oscillating in a similar manner (Grabner *et al.* 1977). As shown in Figure 3, correlated neutron fluctuations at different detector positions *D* can be directly determined as an average function in a time domain. In the form of a Lissajous

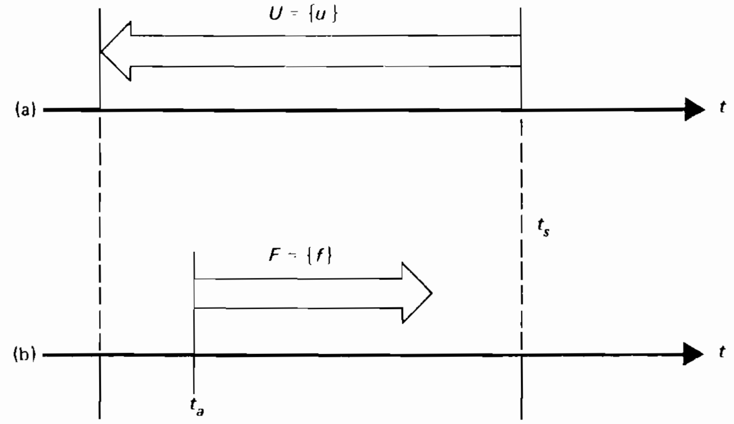

Figure 1. Time scales for accident analysis: (a) 'post-mortem analysis after the occurrence of an accident; (b) early detection of malfunctions.

figure they give an instructive impression of the trajectory of the center of gravity of the moving elements (Grunwald *et al.* 1978). However, this method is too complicated for continuous monitoring.

Sound signals from the guide tubes of control elements are better suited for a simple monitoring procedure. These signals can be used to classify each element by degree of suspicion. Using continuous monitoring, it has been possible to avoid putting control rods into a critical position, as well as to prolong the time of operation. All rods are now controlled by a hardware monitoring device.

Monitors for coolant pumps are currently being developed, and monitors for loose parts are being tested. All monitors are hybrid-type devices and contain the same parts, such as passband filters, amplitude or sign discriminators, pulse counters, shift registers for one-bit information, and computer links. This is important for keeping the costs of monitors low.

Before concluding this discussion, I should mention that after an accident has occurred noise signals can supply crisis management teams with valuable information about the conditions of reactor components; this was shown during the Harrisburg event. C.W. Mayo (1979) drew attention to this possibility in a report presented to the 12th Informal Meeting on Reactor Noise Analysis.

Of course, when a reactor is in a shutdown mode the spectra of most noise detectors differ from those obtained during operation. But investigations into these differences, for instance in the case of in-core detectors, can provide important core

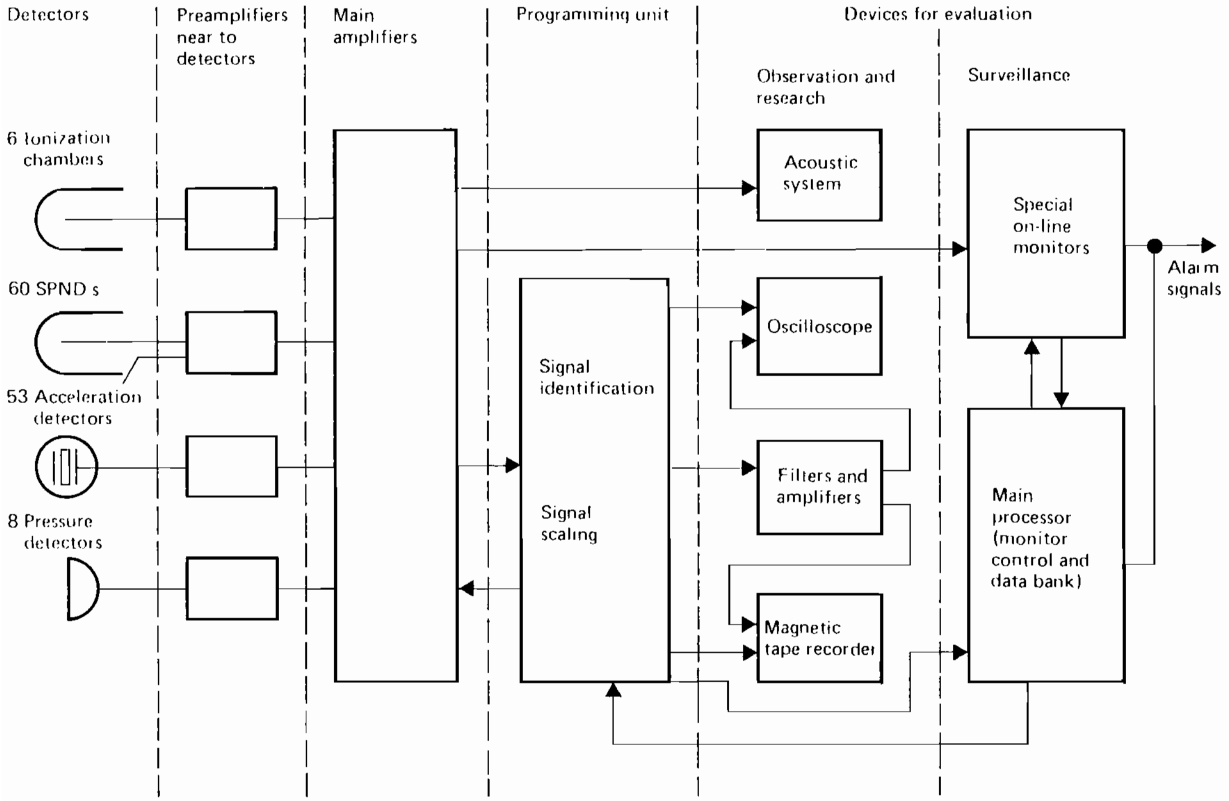

Figure 2. A block scheme of the RAS-II noise analysis system used at pressurized water reactors in the German Democratic Republic.

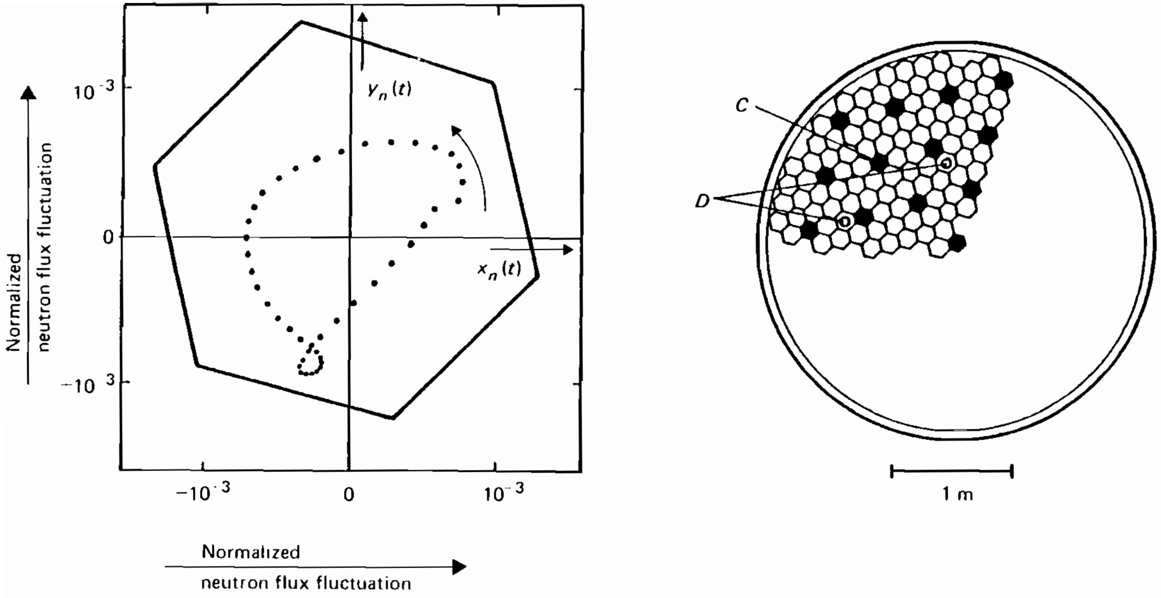

Figure 3. Trajectory of the center of gravity of a moving control element *C*, investigated on the basis of neutron fluctuations at detector positions *D* using special correlation techniques.

status information. The usual noise diagnostic methods can also be successfully applied in a shutdown situation if noise spectra describing normal behavior are available for comparison. In the case of the TMI-2 accident, observation of the bubble volume in the upper part of the reactor vessel was of particular interest; calculations concerning the behavior of the bubble and its eventual disappearance could be confirmed by observed changes in the pressure noise.

These examples show that noise diagnosis can become an important method for early detection of malfunctions in nuclear power plant operation. Noise signals can also be important for obtaining information on the status of the plant after the occurrence of an accident.

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PLANNING FOR RARE EVENTS: NUCLEAR ACCIDENT PREPAREDNESS AND MANAGEMENT

Proceedings of an International Workshop
January 28–30, 1980
John W. Lathrop, Editor

The nuclear reactor accident at Three Mile Island in 1979 presented several surprises to those concerned with nuclear safety. Some features of the accident have been studied in depth — such as problems with operator training, instrumentation, and mechanisms for learning from past accidents — and have led to corrective actions. Yet one of the most significant features of TMI has received much less attention: the degree of confusion surrounding the management of the accident, including the confusion marking evacuation decisions.

The accident revealed the severe problems of maintaining an accident management system capable of quickly determining and executing population protection measures. This problem is compounded by the rarity of nuclear accidents; preparedness must be developed and maintained on the basis of scarce experience, without authentic testing, and in spite of the poor incentives presented to many of the individuals involved.

Recognizing the need for a critical look at these problems, the Management and Technology Area of the International Institute for Applied Systems Analysis (IIASA) convened a Workshop on Procedural and Organizational Measures for Accident Management: Nuclear Reactors. It brought together people who had participated in the management of the Three Mile Island accident, as well as people working to maintain preparedness in seventeen countries. This volume contains the twenty-one papers presented at the workshop and a summary of the themes that emerged during the discussions.

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