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PROCEDURAL AND ORGANIZATIONAL MEASURES TO ASSIST OPERATIONS DURING AN ACCIDENT IN A NUCLEAR POWER PLANT IN EUROPE

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December 1980
WP-80-180

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SUMMARY

INTRODUCTION

This paper is concerned with aspects of organization and procedure in nuclear accident management. Because all accidents can be argued to have common characteristics, a comparative approach is taken here for the discussion of emergency planning for nuclear accidents. This approach reveals several deficiencies in selected European emergency plans, the most important concerning formal and informal communication channels. The most important principle which emerges from this discussion, and which was reinforced by the recent U.S. nuclear accident at Three Mile Island, is that planning efforts should be directed toward reducing the information load carried by each person involved in managing an accident.

THE EVOLUTION OF ACCIDENTS AND THEIR MANAGEMENT

Recourse is made here to the lessons learned from the general field of technologically derived accidents--sometimes referred to as man-made disasters. Firstly, because the majority of organizations which comprise the infrastructure for management of accidents from outside the "boundary fence" are largely identical for all accidents. Secondly, because a detailed study of a variety of technologically disparate accidents has shown that an evolutionary process associated with serious accidents can be identified (Turner 1978). Though no substantial case-record for major nuclear accidents exists, there is no *a priori* reason to suppose that this technology should not show these same general features. Indeed, the record of those few nuclear accidents which have occurred, supports this hypothesis.

This recent examination of the origins of 86 man-made disasters stresses a broad contextual framework containing the following six phases:

- a notionally normal starting point;
- an incubation period;
- a precipitating event;
- the onset of effects or consequences;
- rescue and salvage; and
- full systemic readjustment to the surprise associated with the precipitating act.

Man-made disasters do not originate overnight; it is rare that one individual, by virtue of a simple error can cause an accident in a system formerly believed to be relatively secure. Thus it is crucial that the *incubation period* not be overlooked in anticipating accidents.

In examining *the precipitating-event phase*, information management is seen to play a critical role. Information may not be completely appreciated because individuals, groups, or institutions have a false sense of security or vulnerability when faced with danger signs. Pressure of work for other distractions draw their attention away from the emerging signs of danger. They may distrust the source from which the warning comes. They are sometimes decoyed into concentrating upon one property of a phenomenon and so relegating its other features. Difficulties arise, too, in classifying the phenomenon and in deciding upon a suitable course of action.

A second general problem concerns the organization efficiency of the responding institution. Part of the effectiveness of any organization lies in the way it is able to involve its members with sufficient similarity of approach, outlook and priorities to operate more efficiently than would a group of unorganized individuals. Yet, there remains the danger of collective blinkers masking important issues, referred to by advocates of numerical risk analyses as "the rogue event."

Discrepant events may go unnoticed or be misunderstood as a result of problems in handling information in complex situations. There may be an oversupply of information, the crucial messages may be concealed in a mass of noise or those handling the messages may be busy or preoccupied with other matters. There are further problems of obtaining adequate intelligence, avoiding its dispatch to the wrong people, avoiding distraction in transmission, avoiding the failure to operate on messages or to rely too heavily on informal networks. A chronic problem concerns the individual in an organization who has received all the necessary information about a problem, but who fails to deal with it. Since the recipient may be swamped with information, those attempting to communicate should beware of providing him with all the facts in order to avoid the responsibility of being selective. This idea is a pre-requisite to a good management structure even in non-crisis situations.

NUCLEAR ACCIDENT PHYSIOGNOMY

Nuclear accidents can be described as following the sequence of phases listed above. For each phase, it is useful to identify the groups of individuals who are involved.

In describing the unfolding of events constituting an accident in the nuclear field, "normal" operations consists of a series of re-adjustments by plant and operators to relatively minor deviations from the presupposed and designed flow of operation. Because of this readjustment sequence, or because the aberrant event is hidden within the operation pattern, the response of either mechanism or operator is either non-existant, inadequate, or inopportune: thus, the Incubation Phase. It follows that a fault sequence is set in train. This sequence may or may not, according to the natural laws governing the process, proceed towards an undesired outcome (e.g., the overheating of the reactor core, release of radio-active material, dispersion of this material, etc.). This event may or may not be perceived by the operating staff.

The Precipitation Phase (Phase III of the accident) is generally characterized by a response of the mechanism or of the operating staff to the developing situation. This response will occur with varying degrees of propriety and timeliness and will modify to a greater or lesser degree the course and outcome of the incident. The fourth phase of the nuclear accident is the apparent or explicit manifestation of the accident in terms of events external to the plant or process which menance the operation itself, the plant itself or individuals within the plant boundaries or external to the boundaries. This is termed the resulting-effects phase.

Such typology allows us to develop a categorization of the involved groups as related to the sequence of events. While such a description has a useful role to play in organizing thoughts and opinions on the ideal course of institutional response, it obscures certain vital issues. These include:

(i) the difficulties of allowing for uncertainties in the analysis of incomplete information

(ii) the question of what level of information is useful to the nuclear plan operator and to the external bodies;

(iii) the level of autonomy that must be allowed to each of the actors;

(iv) the assumption in most emergency procedures of rational behavior by operators under stress;

(v) the level of basic knowledge required by the press and others to interpret information; and

(vi) the correct locus of decision for major responses (particularly that of population evacuation and the balancing of potential added risks in executing emergency procedures external to the plant).

Though much can be gained by viewing nuclear accidents as having characteristics in common with a broad range of natual and man-made disasters, it is also important to recognize that which is unique to nuclear accidents and the reaction of the public to them. Otway (1978) provides a number of insights into the uniqueness of the risks from nuclear power.

RESPONSE TO A NUCLEAR ACCIDENT IN SELECTED EUROPEAN COUNTRIES

With this general background, we turn to a discussion of the plans for nuclear accident management in various European countries. Specifically, we examine the emergency plans recommended by the International Atomic Energy Agency (1979), with additional references to plans of the Netherlands (Baas, et al. 1980), the United Kingdom (Matthews et al. 1980), and the Federal Republic of Germany (von Gadow 1980).

In the recent IAEA document on "Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities" it is stated that the unequivocal responsibility for the initial assessment of an accident situation at a nuclear facility rests with the operator. This guideline concerning the initial assessment of an accident situation are followed by each of the three countries selected for study. In this respect, the UK has the most detailed and comprehensive plan, where the lines of authority are clearly delineated from the moment an emergency is encountered.

After the operator has recognized and assessed a potential or actual emergency situation, the IAEA (1979) recommends an interactive response between on-site and off-site authorities. The critical tasks for planning an emergency response include defining accident seriousness, that is, deciding when to initiate what response, and drawing lines of responsibility for making the assessments and for carrying out the interventive actions.

For this purpose, in the Netherlands a distinction is made among three broad accident classes:

(i) Accident Class 1: gaseous radioactive releases above the licensed limit are imminent or taking place, but do not exceed 10 times the value of this limit.

(ii) Accident Class 2: gaseous radioactive releases exceeding a value of 10 times the licensed limit are imminent or taking place whereby the amount of releases can still be approximately estimated.

(iii) Accident Class 3: the unknown amount of radioactive releases, imminent or real, is pointing in the direction of a major catastrophe.

In some European countries emergency plans are oriented to Accident Class 1 with an assumption that there will be ample time between a release below 10 times the licensed limit and a major release. According to the IAEA, there would be sufficient time after events initiating a more serious release to inform off-site authorities so that they could, in turn, implement protective measures prior to the start of any major release to the environment.

The assigning of intervention levels based upon dose commitment is probably the most highly debated issue in the subject of emergency planning. The Federal Republic of Germany (FRG), for example, equates in some detail dose levels with recommended interventive actions. In all cases, it is significant that accidents are defined in terms of dose commitment; the importance of a technical and administrative apparatus for obtaining this data in the event of a nuclear emergency is apparent.

The IAEA recommends that the operator of a nuclear facility set up an emergency response group. This group should assume the leading role in the on-site emergency response organization, particularly with regard to any liaison with the off-site organization. In the United Kingdom, all emergency actions would be directed by an Emergency Team from an Emergency Control Center located at the station administration block, backed up by a fully equipped center at a location off-site. A number of additional teams would also be formed to respond to the emergency.

In the case of a nuclear emergency there are two major responsibilities for off-site authorities: to conduct off-site measurements of radiation levels, and to carry out interventive countermeasures. In the early phases of an accident, the emissions and meteorological data from the nuclear facility should be checked for consistency with the radiation levels measured on the outside. It is, however, emphasized by the IAEA that the initial need to take protective measures should not await this assessment but should be based upon recommendations of the facility operator.

The IAEA document states that it is mandatory for off-site authorities to make arrangements with the facility operator to be provided with prediction of off-site consequences and recommendations for protective measures. The ultimate responsibility for taking these measures usually rests with the outside authorities--with the Mayors of the affected municipalities in the Netherlands, with Public Services in the United Kingdom, and with the local authorities in the Federal Republic of Germany. The IAEA also recommends that an off-site governmental authority should provide for an Emergency Response Organization that would ensure that the necessary plans are prepared and that the responsible authority can carry out action in the case of an emergency.

The IAEA suggests further that procedures require formal acknowledgements of orders and reports. A system for giving priority to emergency communications should be established. In addition, emphasis is placed on the importance of ensuring that individuals and population groups follow the instructions given by the emergency response personnel dealing with the situation. No mention is made, however, of establishing a well-understood vocabulary for communicating the seriousness of the situation and for communicating these instructions.

In England and Wales there is a direct telephone link between the Emergency Control Room and the Grid Control System for off-site organizations; a further direct telephone link exists with the Public Relations Office, which has the function of issuing statements on the situation in collaboration with the CEGB Headquarters Press Offices. To increase the chance that these emergency plans function smoothly, the U.K. Nuclear Installations Inspectorate requires that the nuclear plant staff have a systematic training course and that periodic emergency drills be performed. The Netherlands also appear to have an adequate communication system, at least in terms of the technological links. There exist cable and radio connections including a number of reserved telephone lines. Again, however, no mention is made of developing unambiguous language or code for ensuring that the human component of the system functions adequately.

Though the recommended plans of the IAEA, and the existing plans of the United Kingdom, the Netherlands, and the Federal Republic of Germany, are admirable in their clarity and detail, they suffer from two major flaws. In general, plans are designed to handle only one type of accident--a clearly defined release. Neither the slowly developing accident, where the possibility of a major release is uncertain, nor the unexpected and immediate catastrophic release are included in any comprehensive way.

The second flaw is that inherent in the plans reviewed here, including the IAEA recommendations, is the assumption that all procedures will work more or less smoothly. Thus, for example, if emergency telephone lines exist between the Emergency Control Room and off-site authorities, it is assumed that meaningful communications will be transmitted. Little thought is given to the possible human problems.

LESSONS LEARNED FROM PREVIOUS ACCIDENTS

Lessons learned from the TMI accident should be treated with caution as the next accident will not be the same as TMI, and the emergency organization of any European country is importantly different from those organizations in the US. Yet, the TMI accident revealed a type of nuclear accident not anticipated in the plans studied to date: a confusing, slowly developing accident with resulting uncertainty about current and future plant status. This type of accident could happen in a European country; thus, emergency plans should be designed to handle such a occurrence.

One of the most recurrent findings in the documents examined (President's Commission 1979; Rogovin 1979; US Nuclear Regulatory Commission 1979a-c) was the need for an appropriate organization for the operator team. The operators must be presented with clear, well-organized, and screened information in a non-distracting environment, with a well-defined chain of common information sources and sinks. The European authorities are better prepared in this respect; yet, some insights can be gained from the US recommendations.

The operators should be able to concentrate on stabilizing the reactor and comprehending the system status. All other accident management operations should be kept separate--physically, acoustically, and organizationally (Rogovin 1979).

Communications were a serious problem at TMI, largely because the plant status was not well understood. There were no summary descriptors that could be used to describe the technical situation. On this subject, most of the lessons and recommendations included in the Kemeny (President's Commission 1979) and Rogovin (1979) reports were particular to the US organizations involved. The following general lessons can, however, be gleaned from the reports.

(i) Information sources should be clearly specified, including who collects what information on-site and off-site as well as who coordinates off-site data collection activities.

(ii) Information dissemination to off-site agencies and the media should be clearly specified and conducted by appropriately trained people. The European plans seem especially weak in this regard.

(iii) The people involved should be appropriately trained.

The concept of keeping operator and non-operator activities separate applies as well to the operator team. Lines of responsibility should be clearly laid out, including the lines between the shift supervisor and the shift technical advisor.

Many of the above organizational measures presume a long-term accident such as the one at TMI. Yet, these measures must not be taken in such a way as to degrade the effectiveness of emergency operations in the case of a short-term accident.

TMI presented a clear need for unambiguous emergency procedures to deal with abnormal operations and a poorly understood plant status. Emergency procedures must be clearly defined, even in the face of great uncertainty (US NRC 1979b).

A central problem in emergency planning is maintaining operator preparedness (Otway et al. 1980). One solution often mentioned is the use of improved simulator training and of repeated simulator experience, designed to include accidents involving multiple causes, complex transients, and long-term developments (Rogovin 1979). Another measure is plant drills for the same types of accidents, with closely watched operator performance and operator rewards for good performance (US NRC 1979b).

COMMUNICATIONS BETWEEN THE OPERATOR AND THE OUTSIDE WORLD: THROUGH THE CONTROL ROOM WALL

The communication links between the operators in the control room and those outside are critical to the smooth functioning of the emergency response. An analysis of the technical sources the operators call upon for assistance and the government authorities that depend upon the operator team as a source of information for their accident management decisions are chosen as focal points because analyses of the experience at Three Mile Island indicate that communication was a central problem and because European plans also appear weak in this regard. The report on the investigation by the U.S. NRC's Office of Inspection and Enforcement (1979a) concluded that *the provision of substantive technical support to the management team directing emergency actions on operational matters suffered primarily as a result of communication difficulties.*

This report cites as a reason for this problem the fact that emergency planning was geared to those major accidents where events occur very quickly--as are the European plans. It may be that in these countries lines of duty are not so well defined and communications are possibly not adequate for the slowly developing accident. At TMI this orientation led to a lack of emphasis on mechanisms to mobilize and communicate with off-site personnel. While it is likely that the next nuclear accident will not be like TMI, and while there are important differences in emergency organizations between the US and European countries, the fact remains that the role of the operator in emergency operations may be determined by the communications links, and those links should be examined for their effectiveness in the unexpected accident type discovered at TMI: a confusing, slowly-developing accident.

Communications with Technical Sources: Information Source for the Operator Team

There are several types of technical resource people who may be useful in accident management. However, selection procedures should respond to the problem presented in the Rogovin (1979) review of the TMI accident: what is desired is one person with both great technical expertise and complete day-to-day familiarity with the plant, yet few people exist with both of those characteristics. This applies as well to European operations.

Apart from the problems of selecting and maintaining the availability of technical support staff, there are general problems of communication between them and the operator team. The most important of these include:

(i) Operator Resistance: There are several reasons why the control room crew may fail to communicate to the outside world as effectively as it should. These include: technical, psychological, procedural and incentive factors.

(ii) Delays: The TMI accident showed that it is easy to underestimate the delay in communication. Since accident management often cannot afford to wait for the appropriate expert or desired calculation, the problem of delays in communication gives rise to the need to make decisions in the face of great uncertainty. Planning for decisionmaking under uncertainty is not adequately addressed in the emergency plans studied to date.

(iii) Signal-to-Noise Ratio: Another difficulty with communications is brought about by the volume of messages passing back and forth in a confusing accident such as the one at TMI. The acknowledgement and retrievable storage of information can fully tax the mental resources of the operator team.

(iv) Limited Usefulness of Technical Support: The experience at TMI shows that even with extensive expert technical consultation over hours and days of deliberation, a great deal of uncertainty in system status persisted. Several key areas of misunderstanding or lack of understanding persisted for days at TMI, even with a veritable army of America's best technical minds assembled at the site.

In the case of nuclear accidents, the decisions made by government authorities include both the choice of which countermeasures to implement (shelter, evacuation, thyroid blockers, warning, no action) as well as the choice of where it should be implemented (radius, sector). Risks and costs are associated with implementing a countermeasure whether or not a release occurs, just as there are risks for not implementing countermeasures if a release does occur. Thus, the decision to order a countermeasure involves a balancing of social and political risks and costs. This is usually complicated by the fact that technical experts and government authorities, both with limited expertise, are involved.

It is usually assumed that an accident can be defined in terms of a release; the operator's duty is to assess the severity of this release and with this information the responsible authorities can order the appropriate countermeasures. It is important, however, that these guides would not help a operator faced with the situation encountered at TMI, where a hydrogen bubble was discovered in the core. This accident shows that countermeasure decisions may have to be made in the face of great uncertainty. The critical question which has not been addressed is how the operator can communicate this uncertainty.

A Suggestion for Improving Communications

Part of the philosophy of emergency procedure design and accident prevention should be based upon past experience. Though every effort should be made to prevent recurrence of past accidents, it would be irresponsible to acknowledge that not every failure which is *a postiori* obvious could have been obvious *a priori*. New regulations stemming from past experience tend to deal with a well-structured problem defined and revealed by the accident, rather than the ill-structured problem existing before the event.

Because the situation before the event is often ill-structured, a first priorty is to counteract the problem of information overload on the operator. For this purpose, accident management information could be ranked and screened so that only the most important and appropriate information gets to the operator team, with the rest of the information shunted to data recorders and support groups in different rooms. A second problem introduced above, is that of coping with a poorly structured and uncertain situation. How does the operator convey an uncertain plant status to outside authorities?

One possibility suggested by a growing school of thought on the use of probabilistic information, is to train the operator in the use of subjective probability. Ideally, the operator or technical experts could express their state of knowledge concerning plant or accident status in terms of a set of subjective probabilities. The government authorities could, in turn, be briefed on the use of these probabilities, specifically in how they translate into action. This scheme, though simple enough on paper, would probably not work in an accident situation since in the midst of an accident, the operator team probably could not meaningfully set subjective probabilities; and government authorities cannot be expected to understand and be comfortable enough with subjective probabilities to combine such information appropriately with social and political value information to come to an appropriate countermeasure decision.

As a possible way around this difficulty, this pre-determined language could have as a vocabulary, not probabilities, but simple key- words or colors ("condition red") or numbers and these keywords could be associated with, say, from three to ten standard paragraphs.

Ideally, this Standard Language System (SLS) would induce the operator to move from very coarse aspects of system status to a particular paragraph. For this purpose, the mapping from system status to paragraph must be unambiguous. The operator could then be held liable if, for instance, he transmits a particular plant status incorrectly, since post-accident hearings could reasonably determine that he should have been able to assess it correctly. The SLS also relieves the operator of some of his responsibility, in that he can refer to the mapping guidelines; using the SLS, he is called upon to exercise his judgment less.

Ideally, the SLS would also induce the government authority to act upon the paragraph received with a particular countermeasure. Given the paragraph received and extenuating circumstances, the authority must feel that only one or two countermeasures could be justified in post-accident hearings. The authority is also relieved of some of its responsibility, since it can cite the paragraph given as partial justification of the decision.

The SLS allows the structured "pre-digestion" of very difficult judgements and decisions that could not be made well in the heat of an accident. The net effect would be to decrease *ad hoc* human judgments in accident management, replacing them with more carefully considered judgments. The SLS would also provide an appropriate avenue for openness, and so would help prevent the loss of credibility that so complicated the TMI accident. Finally, the SLS would build into the accident management system a pre-determined means of describing and reacting to a very uncertain plant status, both current and future.

One would expect, however, some difficulties in the development of an SLS, including keeping the mapping from system parameters to paragraphs simple enough to be appropriate for a stress situation; keeping it general enough to allow for unexpected events; keeping it of a manageable size; formulating clearly defined system status to action response; and keeping it up-to-date.

PRINCIPLES FOR ASSISTING NUCLEAR ACCIDENT MANAGEMENT OPERATIONS

Basic principle points to be followed in planning for nuclear accident management can be gleaned from the preceding. They are viewed from the perspective of the operator. The principle that underlies all the others is that all planning efforts should be directed toward reducing the information processing load carried by each person involved in managing an accident. A lesson learned from previous accidents is that there is a very large amount of information requiring rapid and appropriate response. The individual information processing load can be reduced substantially by two planning measures:

(i) by giving each person a clear and specific role within a well-understood information processing structure;

(ii) by anticipating as many accident management decisions as possible in the planning process.

Thus, real-time, *ad hoc* decision making can be reserved for unexpected features of the accident. These fundamentals form the basis for a further eight more specific principles.

Structure

1. *Lines of Authority and responsibility should be clear and complete.*
2. *Lines of communicaton should be clear and complete.*

Information Management

3. *Active information management should be imposed on all lines of communication.*
4. *Separable operations should be kept separate, in separate rooms, with different operations.*

Aids to Individuals in the Process

5. *Accident management staff should be selected to combine technical knowledge, plant familiarity, and availability.*
6. *Operators and other decision makers should be offered appropriate incentives for decisions.*
7. *Procedures should be transparent and unambiguous, even in accident situations.*

Management Under Uncertainty

8. *Communications and procedures must be specifically designed to help people make decisions under extreme uncertainty.*

CONCLUSIONS

In addition to the principles listed above, other general remarks can be made here in smmary form.

Similarity of Accidents

A study of several non-nuclear accidents found that there are broad similarities in the structure and development of major accidents. This is a very important finding, as the key problem in planning for nuclear accidents is that they are extremely rare.

Information Management

A second conclusion is that information management plays a central role in accident management. The cues preceeding an accident rise out of a background of inconsequential fluctuations in performance. Their early identification, then, is a signal detection problem. Even after identification, the accident management problem can be characterized as an information processing problem: the attempt to react appropriately to a very large amount of information in a short time.

Planning to Deal with Uncertainty

The most basic and important conclusion arises frm a comparison of the accident at Three Mile Island in the US, and the plans for nuclear accidents in some European nations. Current plans do not appear to plan adequately for poorly understood, slowly developing accidents where there is a great deal of uncertainty about the current and future status of the system. This is in part due to the fact that it is extremely difficult to plan for a rare event, and to verify that the planning is adequate. Past accidents, seen through the lens of hindsight, are typically studied as a well-structured series of events. Future accidents, as represented in drills, are typically represented again in a well-structured manner. An actual future accident may well be ill-structured and poorly understood. That uncertainty led to great difficultes in communications and decision making.

Clearly, accident planing should help operators cope with uncertainty of the sort experienced at TMI. Yet a study of past US and some European plans finds that they have been based on the assumption that a serious accident would be initiated by a recognizable and distinct event that gives, at least, a confident and low bound to the maximum release in the near future. Accidents in those plans are characterized in terms of doses, countermeasures are then dictated at particular dose levels. The plans do not seem resilient to the confusion and uncertainty of a poorly understood accident. Past accidents show that individuals have difficulties in recognizing, comprehending, and dealng with an accident, especially so when a great deal of uncertainty is involved. A standardized language, all designed to help cope with uncertainty, is required. That aspect of nuclear accident management does not appear to be adequately addressed in the plans studied.

General Summary

It is possible to draw together certain conclusions which may be useful in the eventual formulation of recommendations. To revert to the illustration of accidents laid out in the introduction these latter would represent some of the "new norms" of Phase VI. In summary, the conclusions are:

1. Accidents, nuclear or other, can be argued to have common characteristics and structure.
2. This structure allows certain comparative observations to be made, particularly with respect to communications.
3. Effective, though appropriately limited, communications are vital to the handling of accident situations.
4. The efficiency of the appropriate communications depends upon a complex of factors--institutional and administrative, social and psychological.
5. Recognition that accidents may occur outside the preconceived band of possible characteristics and structures is necessary.
6. Use may be made of the TMI accident experience to improve existing European contingency plans in certain areas.

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PROCEDURAL AND ORGANIZATIONAL MEASURES TO ASSIST OPERATIONS DURING AN ACCIDENT IN A NUCLEAR POWER PLANT IN EUROPE

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I. INTRODUCTION

This paper is concerned with aspects of organization and procedure in nuclear accident management. In addressing this topic, recourse is made to the lessons learned from the more general field of technologically derived accidents--sometimes referred to as man-made disasters. This approach is valid for two reasons. Firstly, the majority of organizations which comprise the infrastructure for management of accidents from outside the "boundary fence" are largely identical for all accidents. Secondly, a detailed study of a wide variety of technologically disparate accidents has shown that a general evolutionary process associated with serious accidents can be identified (Turner 1978). Though no substantial case-record for major nuclear accidents exists to date, there is no *a priori* reason to suppose that nuclear technology should not show these same general features. Indeed, the record of those few nuclear accidents which have occurred, supports this hypothesis.

In the first part of this study we analyze various phases of accident evaluation and accident management. We attempt, in the second part, to point to some procedural and organizational measures which are likely to be particularly important to operations during a nuclear accident.

For this purpose, we shall review existing European plans, making reference to the accident at Three Mile Island (TMI) in the United States (US), in order to identify the roles of the different groups involved. Special consideration will be given to the relationship between utility operators and technically competent external bodies for the TMI and other accidents.

The Evolution of Accidents and Their Management

Current planning tends to attribute a somewhat unique character to nuclear accidents, paying perhaps too little attention to the fact that in the wider context of the technological world common features conspire from time to time to cause accidents. A broader, generic approach to accidents should thus be instructive.

One important feature common perhaps to all technologies is that in accident planning and investigation, the engineer's thinking may dominate. Interpretations have been almost exclusively technically oriented with only scant attention given to social and administrative aspects.

Disasters other than those arising from natural forces or sabotage are not created overnight. It is rare that an individual, by virtue of a simple error can cause an accident in a system formerly believed to be relatively secure. Though the majority of examinations of the long-term development of accidents have supposed them to originate in a bolt from the blue. A recent examination (Turner 1978) of the origins of 86 man-made disasters stresses a broad contextual framework consisting of the following six phases:

-- a notionally normal starting point;

-- an incubation period;

-- a precipitating event;

-- the onset of effects or consequences;

-- rescue and salvage; and

-- full systemic readjustment to the surprise associated with the precipitating act.

These phases are illustrated in Figure 1. Of special interest is the beginning at point "a," which is where aberrant events begin to accumulate unnoticed. The incubation period ends at "b," where a precipitating incident produces a transformation, revealing the latent underlying structure. A situation which had been presumed to have one set of properties is now revealed as having different and additional properties. Attention is usually focused on the precipitating event because of its immediate characteristics and consequences. This makes it almost inevitable that the general perception of the aberrant events in the incubation period will be modified. Yet, if appropriately sensitive monitoring devices and techniques are used, it may be that sensory evidence of the incubation can be built up. Nonetheless, measures designed to indicate the onset of an accident or to deal with its development will not provide help in anticipating latent faults.

To prevent accidents we need to be aware of the appropriate time of each point in the incubation network so that:

-- ambiguities can be clarified;

-- information is not overlooked;

-- information for controlling complex situations is provided, and

-- information needed to foresee "unknown" situations is at hand.

Unfortunately not all of these requirements can be wholly fulfilled. For this reason, during the course of an accident, it is necessary to adjust continuously for the discrepencies between what the disaster plan envisaged and what is really happening.

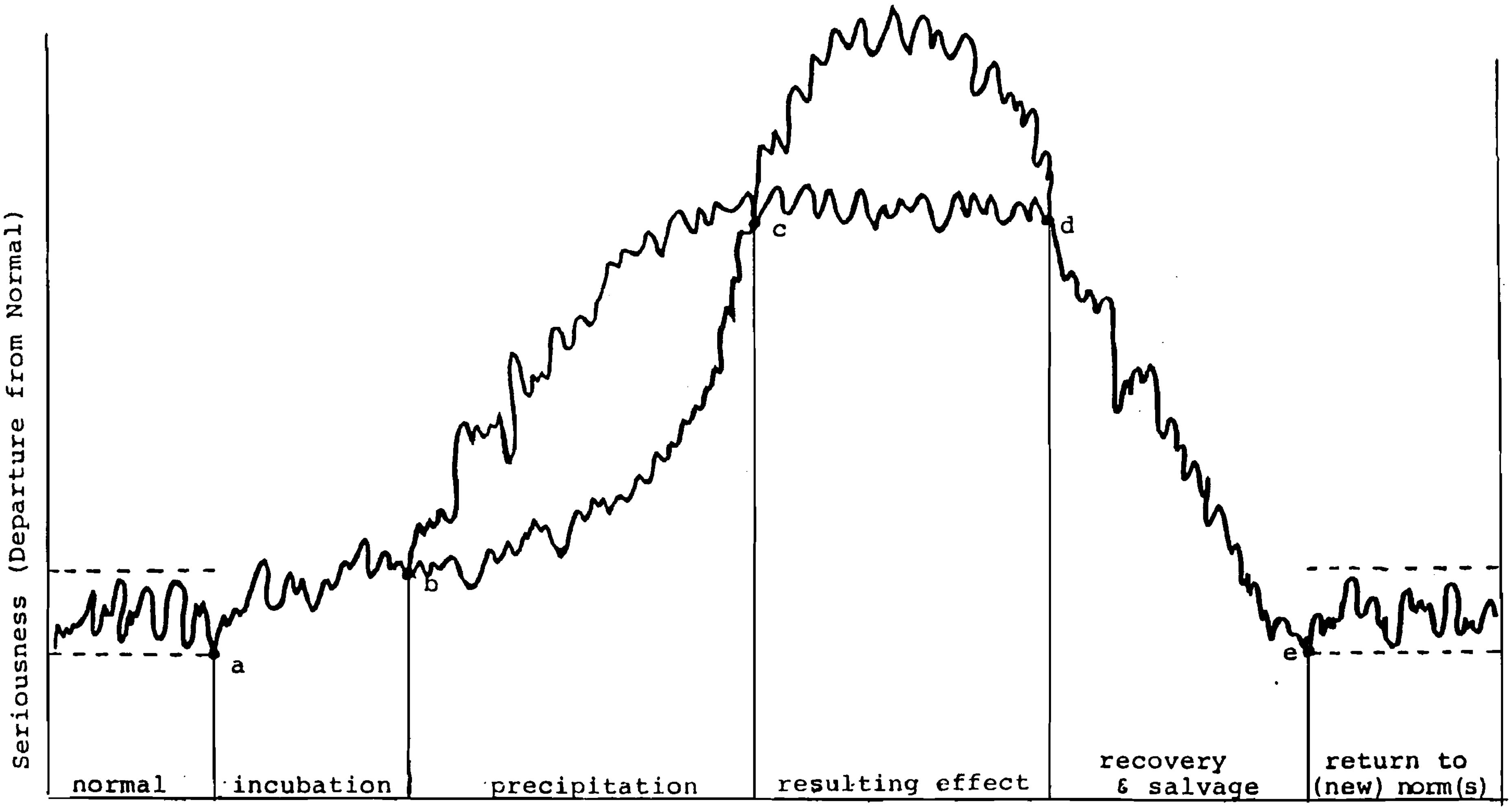
A Need to Examine the Incubation Phase

Accident inquiries can be useful for establishing patterns of appropriate communication and points for intervention. Authorities making these inquiries are generally concerned with the behavior of and decisions of individuals and organizations contributing to the event in question as well as to the technical, social, and administrative changes needed to prevent a recurrence. However, recommendations resulting from these inquiries have often imposed overly stringent and inoperable conditions on the institutions concerned. This has, in turn, resulted from a failure to understand the Incubation Phase.

The problem of understanding the origins of accidents is essentially that of identifying events unanticipated by those pursuing orderly objectives. The problems of explaining the events preceeding and surrounding accidents are those of accounting for biases and inadequacies in habitual ways of dealing with information relating to the impending accident. General recognition of the need for a new interpretation of the situation is usually produced by the immediate physical characteristics of the precipitating event, which may be purely human or purely technical (inactive)--as when an explosion, fire, or a crash occurs, or a component finally breaks. Finally, the precipitating event has links with many of the causes of aberrant events in the incubation period, since just as a positive organizational achievement requires a chain of correct acts and decisions if it is to be of any significance, a large accident requires an extensive chain of errors. A simple error leading to a simple accident is readily explicable, traceable, and understandable; however, large-scale disruptions are usually not caused by a simple error but by an accumulation of simple errors.

A Need to Examine the Precipitating Events and Resulting Effects Phases

This chain of precipitating errors includes not only technical failures in information flows, communication channels, organizational structures and personnel motivations. A brief overview of the general problems is presented now. The remainder of this report will concentrate



Phases I II III IV V VI

Time (Non Dimensional)

point a. start of incubation
b. accident becomes apparent
c. gross damage--injuries and deaths
d. control obtained
e. return to normal

Figure 1. Phases of "Accident" Development

on the more specific problems involved in nuclear-accident preparedness in the context of U.S. and European experiences.

The first problem concerns the role of information in accident assessment and response,

why it is not fully appreciated or understood. Information may not be completely appreciated because individuals, groups, or institutions have a false sense of security or vulnerability when faced with danger signs. Pressure of work for other distractions draw their attention away from the emerging signs of danger. They may distrust the source from which the warning comes. They are sometimes decoyed into concentrating upon one property of a phenomenon and so relegating its other features. Difficulties arise, too, in classifying the phenomenon and in deciding upon a suitable course of action. Plant operators may have difficulty in identifying the information providing event amongst a mass of irrelevant material. Sometimes there is the added difficulty of convincing those in power of the validity of the information. Frequently the available information is not assembled in the appropriate form or place.

To assemble information which should pass among different organizations and institutions, use may have to be made of non-routine, non-institutional patterns of communication. Where communication itself sets up barriers to the flow of information, these barriers may be such that they make it impossible to stop the disaster occurring. Of course, it is impossible and undesirable for everyone to communicate everything to everyone else, but due attention must be paid to the screens through which information flow is essentially filtered. It is especially important to recognize that, often, individuals are reluctant to admit the existence of a potential accident situation.

A second general problem concerns the organization efficiency of the responding institution. Part of the effectiveness of any organization lies in the way it is able to involve its members with sufficient similarity of approach, outlook and priorities to operate more efficiently than would a group of unorganized individuals. Yet, there remains the danger of collective blinkers masking important issues, referred to by advocates of numerical risk analyses as "the rogue event." When a pervasive and structured set of beliefs biases the knowledge and ignorance of an organization and its members, these beliefs not only show up in the attitudes and perceptions of those within the organization but they also affect the decisionmaking procedures within the organization (Turner 1978).

In general, at any point of possible inhibiting action, contradictory orders by individuals could change the course of events. Yet, it would be an over-simplification to think that the accumulation of circumstances which produce or inhibit accidents increases with the number of individual actions. Individuals are involved but there are not many isolated, unconstrained individuals. It is organizations that generally have a continuous role in disasters, and most of the individuals concerned in the events which comprise the incubation network which are operating in institutional roles.

Organizations attempt to act rationally; but they can never be fully rational as this would imply omniscience. Rather, organizations must settle for being intendedly rational; thus, acknowledging bounds and limitations. They achieve concerted action by establishing and monitoring agreement amongst their members that certain possibilities, issues and contingencies are important and relevant to organizational decisionmaking, while others may be ignored without incurring official disapproval. For this reason, the possibility arises that those contingencies which are ignored may turn out to be more hazardous than expected.

A further problem encountered in the accident-management realm is the mobility of the responsible personnel to cope with a non-routine set of events. By accident definition, management's efforts to eliminate the hazard have failed. It is faced with the immediate problem of implementing the disaster plan and monitoring and controlling the situation under crisis conditions. Deficiencies of disaster plans constructed to meet the hypothetical emergency situation may become apparent, forcing the local manager to make rapid adjustments and corrections.

There is nothing intrinsically special about this type of management role; many organizations specialize routinely in dealing with other peoples' disasters, e.g., the Royal National Lifeboat Organization in the UK, the Red Adair Organization, Fire Brigades, etc. Yet, the general experience relates to accidents occurring infrequently but sufficiently often that most managers will encounter minor crises routinely. Consider for example, the chemical or refining industries, or the airline industry where engine malfunctions are not routine but occur with sufficient regularity for pilots to be aware of the drill from first-hand experience. Though possible remedies to this problem, such as staging mock drills or requiring that a highly-qualified scientist be available for the unexpected major accident are discussed in a later section, it is worth noting here that general experience in other industries indicates that the right man-on-the-spot is one who has had past experience in *ad hoc* command rather than a highly-qualified technologist.

Turning to the last, and perhaps most important, link in the chain of events leading to an accident, we shall look at the role of information. For discrepant events leading to a disaster to accumulate, they must go unnoticed or remain misunderstood. Though this is usually a result of erroneous assumptions, past errors have also been neglected because complaints from non-experts outside the organization were too readily disavowed as uninformed.

Discrepant events also go unnoticed or are misunderstood as a result of problems in handling information in complex situations. There may be an oversupply of information, the crucial messages may be concealed in a mass of noise or those handling the messages may be busy or preoccupied with other matters. There are further problems of obtaining adequate intelligence, avoiding its dispatch to the wrong people, avoiding distraction in transmission, avoiding the failure to operate on messages or to rely too heavily on informal networks. A chronic problem concerns the individual in an organization who has received all the necessary information about a problem, but who fails to deal with it. Since the recipient may be swamped with information, those attempting to communicate should beware of providing him with all the facts in order to avoid the responsibility of being selective. This idea is a pre-requisite to a good management structure even in non-crisis situations.

Where the information indicating an accident is completly unknown and unexpected, it is clear that little can be done. Yet, in practice, disasters arising from such completely unknown unsuspected sources seem to be very rare, particularly in the 20th century. In almost all cases, the prior information exists somewhere. There is a clear need to explore the usefulness of better search procedures. Planning documents, emergency procedures, reports of malfunctions, accidents or incidents in similar plants or similar technological situations elsewhere should be dealt with, ranked and transmitted in a creative fashion.

II. NUCLEAR ACCIDENT PHYSIOGNOMY

Having discussed the character of technological accidents in a general sense, we turn to exploring these concepts as they relate to the technology of nuclear power. In this section, we develop two main concepts in terms which allow elucidation of the flow of information necessary for adequate response to accident conditions. These are:

1. Description of the time sequence of a nuclear accident in several phases; and
2. Recognition of the several groups of individuals who are involved either by their function in the normal management of electrical power production from nuclear fission or by their necessity to respond to particular accident features.

As discussed in the general case above, in describing the unfolding of events constituting an accident in the nuclear field, "normal" operations (Phase I of Figure 1) consists of a series of re-adjustments by plant and operators to relatively minor deviations from the presupposed and designed flow of operation. The recognition of events which are the precursors of serious malfunction of the whole process is done against the background of this minor readjustment pattern. This fact is particularly important when considering the ideal response by the relevant groups or organizations who will be involved. These groups will attempt to control and contain the disruptive elements in the processes and to mitigate the effects and return the system to its initial course.

Because of this readjustment sequence, which was reviewed at greater length in the Introduction, or because the aberrant event is hidden within the operation pattern, the response of either mechanism or operator is either non-existant, inadequate, or inopportune: thus, the Incubation Phase (see Figure 1). It follows that a fault sequence is set in train. This sequence may or may not, according to the natural laws governing the process, proceed towards an undesired outcome (e.g., the overheating of the reactor core, release of radio-active material, dispersion of this material, etc.). This event may or may not be perceived by the operating staff.

Again referring to Figure 1, the Precipitation Phase (Phase III of the accident) is generally characterized by a response of the mechanism or of the operating staff to the developing situation. This response will occur with varying degrees of propriety and timeliness and will modify to a greater or lesser degree the course and outcome of the incident. For the purposes of describing appropriate overall response it is assumed that this precipitating or evolutionary phase proceeds, with only secondary or minor modification, towards an undesired outcome. The fourth phase of the nuclear accident is the apparent or explicit manifestation of the accident in terms of events external to the plant or process which menance the operation itself, the plant itself or individuals within the plant boundaries or external to the boundaries. This is termed the resulting-effects phase when referring to Figure 1.

Such typology allows us to develop a categorization of the involved groups as related to the sequence of events. Their ideal, or moderately appropriate, response can then be suggested. Typical periods for each of the phases can be derived from considerations of nuclear physics and engineering. For instance, a range of typical values suggested by the International Atomic Energy Agency (IAEA) are shown in Table 1. The kind and timing of information flows between the involved groups can also be related to the timing of the events themselves and to the possibilities afforded by the nature and location of the groups.

Within the organization owning and operating the plant certain groups can be defined. These consist of:

(i) the plant staff, itself, responsible for normal operation and divided into those actually on duty and controlling the plant, and those available, but off-duty;

(ii) auxiliary or advisory staff in each of these categories; and

(iii) experienced staff in a headquarters, central or regional location, consisting of designers, operation staff and safety experts.

There are also groups external to the operator's organization, consisting of:

Table 1. Guidance on Initiation and Duration of Release

PERIOD	TYPICAL RANGE
Time from the initiating event to start of atmospheric release	0.5 hour to one day
Time period over which radioactive material may be continuously released	0.5 hour to several days
Time at which major portion of release may occur	0.5 hour to 1 day after start of release
Travel time for release to exposure point (time after release)	8 Km / 5 Mi / - 0.5 to 2 hours 16 Km / 10 Mi / - 1 to 4 hours

Source: IAEA

(i) similar categories of staff in analogous organizations;

(ii) design staff in the manufacturing company, and

(iii) staff in the regulatory authority with experience in the design, operator or safety analytic field.

In addition, there exists staffs in other relevant industries, having operational, design and safety experience or having access to equipment and supplies. Finally, there may be a relevant category of professional staff with experience in the handling of emergency situations affecting the general public, the general public themselves, and the dissemination media. The involvement of these groups can be characterized in terms of their responsibility for:

(i) the response to the incident, either immediately within the plant or at longer terms within the plant;

(ii) the actions external to the plant; or

(iii) the communication of the relevant information to those affected for their protection.

Information derived from the plant via the appropriate instrumentation either

-- in plant;

-- external to the plant; or

-- from the historical record;

must be interpreted by certain of the above groups, analyzed and disseminated via the appropriate channels to other groups and finally acted upon by other authorities. In the relatively complex connections of these groups and the level of information available at each stage of the evolution of the accident there lies clearly the possibility of both appropriate and inappropriate action. The degree of responsibility for interpretation, analysis, dissemination and remedial or prophylactic action will vary over time and with the institutional arrangements in different countries.

The involvement of each group follows a pattern which depends upon: (a) circumstances, and (b) necessity and opportunity. The local staff are obviously involved immediately by the circumstances of the event and will probably remain one of the dominant actor groups throughout the incident in as far as plant conditions are concerned. They should at least begin with complete autonomy though this may be diluted if the incident develops seriously and if remedial safeguarding or salvaging actions are required further from the plant. Advisory staff, locally or at headquarters, will become increasingly available. Expert knowledge and assistance may be offered soon after the incident becomes known, but it may be that full use can be made of this only at relatively late stages in the evolution of the incident. In some respects, the introduction of such assistance and advice will become a matter of judgment exercised by central authorities in a similar way as the amount and kind of information offered to the dissemination media. Of course, the serial involvement of the various groups may in practice not unfold as theoretically as it might be predicted.

Thus, while such a description has a useful role to play in organizing thoughts and opinions on the ideal course of institutional response, as discussed in the Introduction, it obscures certain vital issues. These include:

(i) the difficulties of allowing for uncertainties in the analysis of incomplete information (which in turn makes the timing of certain decisions crucial);

(ii) the question of what level of information is useful to the nuclear plan operator and to the external bodies;

(iii) the level of autonomy that must be allowed to each of the actors;

(iv) the assumption in most emergency procedures of rational behavior by operators under stress;

(v) the level of basic knowledge required by the press and others to interpret information; and

(vi) the correct locus of decision for major responses (particularly that of population evacuation and the balancing of potential added risks in executing emergency procedures external to the plant).

Though we began this section with the premise that much can be gained by viewing nuclear accidents as having characteristics in common with a broad range of natual and man-made disasters, it is also important to recognize that which is unique to nuclear accidents and the reaction of the public to them.

There are several fundamental differences between nuclear and other accidents. They stem in large measure from the historical accident of the use of atomic energy as a weapon. At the same time the peculiar revulsion felt by the public for death from radiation is compounded by a fear deriving from the insidious and unfelt nature of radiation and radioactive material. Thus, the fact that radiation affects blood, gonads and future generations give nuclear death a special place in the hierarchy of fears. While it can no longer be claimed to be a "new" form of accident, the prominence it achieved at a point when many technological endeavors were under question, undoubtedly makes it special.

The need to anticipate effects when none are visible and the very nature of the fairly complex precautions that have been foreseen by the relevant and responsible authorities add to public apprehension. The special nature of the public's response to nuclear power has been documented now for many years and only islated cases of calm responses to incidents are recorded though these may be sufficiently numerous in a lean history of major incidents to give some reassurance.

There exists a considerable body of literature (Bignell et al. 1977; Turner 1978) dealing with both on-site and off-site emergency planning. While not denying the usefulness of such material, there is a distinct need to recognize the shortcomings of a response based upon essentially theoretical ideas of behavior. In this report an attempt is made, using the above schemata, to suggest improvements in informational flows taking into account recent accident events and psychological experiments. We recognize, however, the limitations of any attempt at a comprehensive view of disaster management with the present state of knowledge.

III. RESPONSE TO A NUCLEAR ACCIDENT IN SELECTED EUROPEAN COUNTRIES

With this general background, we turn to a discussion of the plans for nuclear accident management in various European countries. Specifically, we examine the emergency plans recommended by the International Atomic Energy Agency (1979), with additional references to plans of the Netherlands (Baas, et al. 1980), the United Kingdom (Matthews et al. 1980), and the Federal Republic of Germany (von Gadow 1980).

Response to a Precipitating Event Phase

In the recent IAEA document on "Planning for Off-Site Responsea to Radiation Accidents in Nuclear Facilities" it is stated that the unequivocal responsibility for the initial assessment of an accident situation at a nuclear facility rests with the operator. This individual is clearly in the best position to make this initial assessment, given familiarity with the operation of the plant and the engineered safety features. This document also assigns the operator the responsibility for initially predicting any off-site consequence of an accident, especially if the accident is serious enough to warrant timely protective measures.

In the case of a release, the operator must predict the resulting off-site conditions by estimating, as soon as possible, the direction, height, and dispersion of any radioactive plume into off-site areas. These off-site conditions may occur immediately after the accident or they may be delayed for a period of time ranging from several minutes to several hours. The estimates regarding the plume, predictions of the potential radiation exposure of the population and the possibilities for contamination of the environment must be communicated to the appropriate off-site authorities as early as practicable by the facility operators so that the appropriate emergency response can be initiated.

These general guidelines concerning the initial assessment of an accident situation are followed by each of the three countries selected for study. An interesting example is the United

Kingdom (UK) where the lines of authority are clearly delineated from the moment an emergency is encountered. The engineer on duty is responsible for alerting the plant officials of a malfunction and/or resulting accident. If an emergency develops, the most senior officer in the plant, usually the Station Manager, would become the Emergency Controller with the responsibility of initiating the emergency organization including an Emergency Health Physicist, an Emergency Reactor Physicist and an Emergency Administrative Officer (each of whom is "on call"). All emergency actions would then be directed by this team. The notable feature of this organizational response is that in the event of an emergency, the responsibility for assessing the extent of the accident and recommending interventive measures is no longer exclusively that of the operator, but that of a team of additional experts. If there is a more senior staff member on duty, the shift change engineer can concentrate on his duties in the control room, leaving the emergency organization to the Emergency Controller and his team.

Response to The Resulting-Effects Phase

After the operator has recognized and assessed a potential or actual emergency situation, the IAEA (1979) recommends an interactive response between on-site and off-site authorities. Depending on the seriousness of the accident, and thus the time available to take the necessary interventive measures, this response might include the following:

(i) activating on-site emergency teams (fire, first aid, etc);

(ii) calling in outside expertise;

(iii) collecting information concerning off-site radiation levels;

(iv) alerting the off-site emergency response teams which would in turn inform the public and initiate necessary precautions; and

(v) sounding the alarm indicating an acute emergency requiring immediate action.

The critical tasks for planning an emergency response include defining accident seriousness, that is, deciding when to initiate what response, and drawing lines of responsibility for making the assessments and for carrying out the interventive actions.

Accident Definition

In the Netherlands a distinction is made among three broad accident classes:

(i) Accident Class 1: gaseous radioactive releases above the licensed limit are imminent or taking place, but do not exceed 10 times the value of this limit.

(ii) Accident Class 2: gaseous radioactive releases exceeding a value of 10 times the licensed limit are imminent or taking place whereby the amount of releases can still be approximately estimated.

(iii) Accident Class 3: the unknown amount of radioactive releases, imminent or real, is pointing in the direction of a major catastrophe.

In the case of Accident Class 1, the Nuclear Operator for the Netherlands Plant must inform the local Mayor, the Nuclear Inspectorate, the Ministry of Social Affairs and the Regional Inspector of Environmental Protection. In the case of a more serious accident, Class 2 or Class 3, the message is transmitted to the Local Mayor, the Nuclear Inspectorate, the Radiation Department and the Regional Alarm Center. The Alarm Center sends the message out to around 25 receiving points.

In some European countries emergency plans are oriented to Accident Class 1 with an assumption that there will be ample time between a release below 10 times the licensed limit and a major release. According to the IAEA (1979):

> studies have indicated that accidents at nuclear power facilities which have a potential for serious off-site effects, would be initiated by an event recognizable to the facility operators and, that with early notification, a period of time would be available for off-site authorities to implement protective measures prior to the start of a major release to the environment of the facility.

As a counterexample, in the United Kingdom all nuclear power plants operated by the Central Electricity Generating Board and the South of Scotland Electricity Board, have a detailed emergency plan "that must be capable of dealing adequately with any feasible emergency situation including those which may give rise to the release of radioactive material or the emissions of ionizing radiations" (Matthews, et al. 1980). The most serious accident considered "feasible" is that of a fuel channel fire in a reactor with a fracture in one of the main coolant ducts. It is expected 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 one to one and half miles of the station (the planning zone has *not* been expanded for this type of accident).

The assigning of intervention levels based upon dose commitment is probably the most highly debated issue in the subject of emergency planning. It is recognized by the IAEA that these levels will depend on social, economic and demographic conditions of the various countries. Examples of intervention levels adopted by several European countries and the US are published in the IAEA document. For example, the Federal Republic of Germany (FRG) equates in some detail, dose levels with recommended interventive actions. In all cases, it is significant that accidents are defined in terms of dose commitment; the importance of a technical and administrative apparatus for obtaining this data in the event of a nuclear emergency is apparent. The possibilities for uncertainties, especially where the release is imminent but not yet realized, is discussed in the next section.

Organization and Responsibility

The IAEA recommends that the operator of a nuclear facility set up an emergency response group. This group should assume the leading role in the on-site emergency response organization, particularly with regard to any liaison with the off-site organization. In the United Kingdom, all emergency actions would be directed by an Emergency Team from an Emergency Control Center located at the station administration block, backed up by a fully equipped center at a location off-site. A number of additional teams would be formed to respond to the emergency. Included are a Health Physics team trained to determine the extent of any off-site contamination, a Fire team, a First-Aid team, an Incident Assessment and Control team led by a trained engineer with the task of making a rapid initial survey of the scene, and a Rescue team. The Emergency team would receive all measurements of on-site and off-site radiation dose-rates, contamination levels, etc., and would be equipped with several systems for communicating with outside authorities.

In the case of a nuclear emergency there are two major responsibilities for off-site authorities: to conduct off-site measurements of radiation levels, and to carry out interventive countermeasures. In the early phases of an accident, the emissions and meteorological data from the nuclear facility should be checked for consistency with the radiation levels measured on the outside. It is, however, emphasized by the IAEA that the initial need to take protective measures should not await this assessment but should be based upon recommendations of the facility operator.

The IAEA document states that it is mandatory for off-site authorities to make arrangements with the facility operator to be provided with prediction of off-site consequences and recommendations for protective measures. The ultimate responsibility for taking these measures usually rests with the outside authorities--with the Mayors of the affected municipalities in the Netherlands, with Public Services in the United Kingdom, and with the local authorities in the Federal Republic of Germany. The IAEA recommends that an off-site governmental authority should provide for an Emergency Response Organization that would ensure that the necessary plans are prepared and that the responsible authority can carry out action in the case of an emergency. Such organizations could include the nuclear licensing authorities, the public health, food and agricultural authorities, weather forecasting services, civil defense, police, medical, hospital, and ambulance services. Again, in the United Kingdom, support arrangements exist for providing additional help and advice, including regional emergency rooms and headquarters, police, fire, and Welfare Services, Ministry of Agriculture, Fisheries and Food, the Atomic Energy Authority, and Meteorological Office. A comprehensive emergency plan for police, fire, ambulance, and welfare services is produced by the county police and the local authority, which is part of the broader plan for dealing with other disasters, e.g., flooding, fire, and major transport accidents.

Communications

The IAEA suggests that procedures require formal acknowledgements of orders and reports. A system for giving priority to emergency communications should be established. In addition, the IAEA emphasizes the importance of ensuring that individuals and population groups follow the instructions given by the emergency response personnel dealing with the situation. No mention is made, however, of establishing a well-understood vocabulary for communicating the seriousness of the situation and for communicating these instructions. This point was stressed in the work referred to earlier, collecting accident histories (Bignell et al. 1977; Turner 1979) in the Introduction.

In England and Wales there is a direct telephone link between the Emergency Control Room and the Grid Control System for off-site organizations; a further direct telephone link exists with the Public Relations Office, which has the function of issuing statements on the situation in collaboration with the CEGB Headquarters Press Offices. The CEGB would operate a Nuclear Emergency Information Room at both the regional and national levels. In addition to reserved telephone links with these organizations, there would be a VHF radio station which would cover a wide area around the nuclear site.

To increase the chance that these emergency plans function smoothly, the U.K. Nuclear Installations Inspectorate requires that the nuclear plant staff have a systematic training course and that periodic emergency drills be performed. In addition, determined efforts are made to keep the public informed of the plans. The most important means of ensuring this is through the setting up of a Local Liaison Committee represented by local inhabitants and organizations and chaired by the Station Manager.

The Netherlands also appear to have an adequate communication system, at least in terms of the technological links. There exist cable and radio connections including a number of reserved telephone lines. Again, however, no mention is made of developing unambiguous language or code for ensuring that the human component of the system functions adequately.

The Limitations

Though the recommended plans of the IAEA, and the existing plans of the United Kingdom, the Netherlands, and the Federal Republic of Germany, are admirable in their clarity and detail, they suffer from two major flaws. In general, plans are designed to handle only one type of accident--a clearly defined release. Neither the slowly developing accident, where the possibility of a major release is uncertain, nor the unexpected and immediate catastrophic release are included in any comprehensive way.

The second flaw is that inherent in the plans reviewed here, including the IAEA recommendations, is the assumption that all procedures will work more or less smoothly. Thus, for example, if emergency telephone lines exist between the Emergency Control Room and off-site authorities, it is assumed that meaningful communications will be transmitted. Little thought is given to the possible human problems. Will the operators disclose all the information? Will they be able to formulate the problem in an understandable manner? To give another example, it is stated that the responsibility for the initial assessment of an accident lies with the nuclear facility operator. What if the operator panics? What if he or key persons on his staff absent themselves? Of course, it will be impossible to devise emergency plans to comprehend all of the "what ifs?", but the point here is that there is a clear lack of attention given to the human dimension of the emergency plans.

It is such problems which were highlighted by the TMI accident and to which we turn our attention in the next sections. In the following section we will take a closer look at communications between the operator and the outside world.

IV. LESSONS LEARNED FROM PREVIOUS ACCIDENTS

Lessons learned from the TMI accident should be treated with caution as the next accident will not be the same as TMI, and the emergency organization of any European country is importantly different from those organizations in the US. Yet, the TMI accident revealed a type of nuclear accident not anticipated in the plans studied to date: a confusing, slowly developing accident with resulting uncertainty about current and future plant status. This type of accident could happen in a European country; thus, emergency plans should be designed to handle such a occurrence.

Organization

One of the most recurrent findings in the documents examined (President's Commission 1979; Rogovin 1979; US Nuclear Regulatory Commission 1979a-c) was the need for an appropriate organization for the operator team. The operators must be presented with clear, well-organized, and screened information in a non-distracting environment, with a well-defined chain of common information sources and sinks. The European authorities are better prepared in this respect; yet, some insights can be gained from the US recommendations.

Separate Operators from Non-Operator Activities

The operators should be able to concentrate on stabilizing the reactor and comprehending the system status. All other accident management operations should be kept separate--physically, acoustically, and organizationally (Rogovin 1979). Here a lesson can be learned from the UK Emergency Response Plan where the lines of authority are clearly delineated from the moment an emergency is encountered. There should be clear, screened lines of oral communication, telemetry, authority, and responsibility between the control room and two other rooms:

1. Emergency Technical Support Center (ETSC): This center could be on-site (US NRC 1979c), but in any case, would be out of the control room. All technical information would be telemetered and displayed in the ETSC, and copies of all updated plant blueprints would be filed there. Technical experts would convene there to assess plant status, formulate the next operation, etc., leaving the operators undistracted to perform current operations. In the UK, this corresponds to the Emergency Control Room.

2. Emergency Operational Support Center (EOSC): This center, which would be on-site, is where various teams of experts, workers, etc., report for duty to be dispatched on particular missions (US NRC 1979c). There is no separate room for this function in the UK plans; all teams report to the Emergency Control Room.

Information

In the words of the Rogovin Report concerning TMI:

> The 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 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 Met Ed/GPU in reporting critical infromation up the management chain and acting upon it....

Clearly communications were a serious problem at TMI, largely because the plant status was not well understood. There were no summary descriptors that could be used to describe the technical situation. On this subject, most of the lessons and recommendations included in the Kemeny (President's Commission 1979) and Rogovin (1979) reports were particular to the US organizations involved. The following general lessons can, however, be gleaned from the reports.

(i) Information sources should be clearly specified, including who collects what information on-site and off-site as well as who coordinates off-site data collection activities.

(ii) Information dissemination to off-site agencies and the media should be clearly specified and conducted by appropriately trained people. The European plans seem especially weak in this regard. At TMI, the appropriate source of information to the media was the utility. However, the uncertain plant status and the lack of appropriate training for the utility spokesperson combined to produce a serious loss of credibility for the utility. As a result, special information dissemination measures had to be taken on an *ad hoc* basis. An informationdissemination plan should specify:

-- who describes plant status to the dissemination media;

-- who gives background, semi-technical, and technical briefings to the media; and

-- who gives accident manatement information to government authorities (Presidents Commission 1979).

(iii) The people involved should be appropriately trained. That is,

-- briefers should be good at explaining the accident situation in non-technical language and at expressing degrees of uncertainty and

-- media representatives should understand the technical concepts involved, should understand probabilities, and should be able to explain these concepts clearly and accurately (President's Commission 1979).

These points are germane to the discussion of all types of serious accidents. The communications between the operator and outside authorities are problematic, and we shall cover them in more detail in the next section.

Lines of Responsibility Within the Operator Team

The concept of keeping operator and non-operator activities separate applies as well to the operator team. Lines of responsibility should be clearly laid out, including the lines between the following two staff personnel (US NRC 1979c):

(i) Shift Supervisor: The Shift Supervisor (Station Manager--UK) should not become involved with each operation; rather, he should keep an overview on the developments. Any administrative duties, whether routine or emergency, should be shifted away from him to outside the control room. A clearly specified successor should take over when the Supervisor is absent from the control room.

(ii) Shift Technical Advisor: The Shift Technical Advisor (Emergency Reactor Physicist--UK) should be as close as possible to that person whom the Rogovin Commission could not find in the US system: a person combining highly technical expertise with plant familiarity.

Many of the above organizational measures presume a long-term accident such as the one at TMI. Yet, these measures must not be taken in such a way as to degrade the effectiveness of emergency operations in the case of a short-term accident.

Personnel

The Rogovin Report (1979) suggests appropriate people to have in various positions in the plant organization. Since this consideration has been discussed in detail elsewhere, it will not be dealt with here except to point out that particular roles for members of the US NRC (1979b) have been proposed. Among these possible roles are:

-- an NRC technical man to be in the control room at all times;

- an NRC technical person to be in the control room at all times and in the chain of command;
- an NRC resident inspector to be on site at all times; and
- an NRC senior person on standby to be flown in.

Procedures

TMI presented a clear need for unambiguous emergency procedures to deal with abnormal operations and a poorly understood plant status. As mentioned above, at the TMI hearing, the operators argued more than half an hour over the question of which actions had been called for by a particular procedure. Emergency procedures must be clearly defined, even in the face of great uncertainty (US NRC 1979b).

Maintaining Preparedness

A central problem in emergency planning is maintaining operator preparedness (Otway et al. 1980). One solution often mentioned is the use of improved simulator training and of repeated simulator experience, designed to include accidents involving multiple causes, complex transients, and long-term developments (Rogovin 1979). Another measure is plant drills for the same types of accidents, with closely watched operator performance and operator rewards for good performance (US NRC 1979b).

V. COMMUNICATIONS BETWEEN THE OPERATOR AND THE OUTSIDE WORLD: THROUGH THE CONTROL ROOM WALL

As discussed in the above section, the communication links between the operators in the control room and those outside are critical to the smooth functioning of the emergency response. In this section the problem is discussed in detail, including an analysis of the technical sources the operators call upon for assistance and the government authorities that depend upon the operator team as a source of information for their accident management decisions. These are chosen at focal points because analyses of the experience at Three Mile Island indicate that communication was a central problem and because European plans also appear weak in this regard. The report on the investigation by the U.S. NRC's Office of Inspection and Enforcement (1979a) concluded:

> The provision of substantive technical support to the management team directing emergency actions on operational matters suffered primarily as a result of communication difficulties. This was evidenced in three ways:
>
> 1. Information (data and plans) transmitted to off-site support, which had been hurriedly mobilized, suffered from time delays. Thus, the off-site groups were dealing with limited historical data.
> 2. The individuals providing data to offsite groups had concurrent duties pertaining to the management of the emergency. The emergency duties always took precedence as would be appropriate.
> 3. The physical communications facilities were inadequate to handle the volume of information requests and transmittals that this kind of accident required.

With the exception of the first problem, the European countries reviewed are reportedly better prepared to meet these difficulties. Yet, the US NRC report (1979a) cites as a reason for the above problems the fact that emergency planning was geared to those major accidents where events occur very quickly--as are the European plans. It may be, then, that in these countries lines of duty are not so well defined and communications are possibly not adequate for the slowly developing accident. At TMI this orientation led to a lack of emphasis on mechanisms to mobilize and communicate with off-site personnel. While it is likely that the next nuclear accident will not be like TMI, and while there are important differences in emergency organizations between the US and European countries, the fact remains that the role of the operator in emergency operations may be determined by the communications links, and those links should be examined for their effectiveness in the unexpected accident type discovered at TMI: a confusing, slowly-developing accident.

Communications with Technical Sources:
Information Source for the Operator Team

Types of Expertise

There are several types of technical resource people who may be useful in accident management. However, selection procedures should respond to the problem presented in the Rogovin (1979) review of the TMI accident: what is desired is one person with both great technical expertise and complete day-to-day familiarity with the plant, yet few people exist with both of those characteristics. This applies as well to European operations. For example, in the UK, how capable is the engineer on duty, who is probably familiar with the plant, in handling a confusing TMI situation? It follows that the technical support team should combine technical experts with plant-familiar people in a form conducive to good collaboration. Six categories of experts can be identified:

- plant operator (engineer on duty);
- plant designer;
- vendor;
- industry;
- licensing agency;
- national energy laboratory staff.

Each of these types has differing strengths in plant familiarity and technical expertise. Details of those relative strengths vary from country to country; in some countries two or more categories can be grouped into one as, for example, the case of only one vendor and one utility company in a nation's nuclear power industry. Since both plant familiarity and technical expertise are valuable, no one category of expert dominates in its usefulness.

The expert categories also differ importantly in their availability. Plant experts can be on-site at all times, or on call within a short time. Other experts may be immediately accessible only by telephone, though continuously manned off-site technical support centers, linked by telemetry, could also be envisaged. Telephone calls can involve long delays. Flying in experts involves even longer delays. Thus, the selection of experts to be part of a technical support group must be tempered by the compromise between level of expertise, delay in availability, and cost and feasibility of maintaining stand-by expertise.

The IAEA recommendations for emergency plans do not assign a role to off-site expertise: "the unequivocal responsibility for the initial assessment of the accident situation at the facility rests with the operator" (1979, p.41). Once more, it is assumed that the accident can be defined as a clearly recognizable release, where the operator, with the use of meteorological data, can predict the off-site consequences. There is no mention of an uncertain development with a potential release, where the operator, himself, may not understand the developing situation.

Problems in Communications with Technical Sources

Apart from the problems of selecting and maintaining the availability of technical support staff, there are general problems of communication between them and the operator team. The most important of these problems are listed below.

Operator Resistance

There are several reasons why the control room crew may fail to communicate to the outside world as effectively as it should. These include:

(i) Technical Factors: As Rogovin (1979) states: "A number of factors...could have accounted for the failure of the control room crew to communicate critical information. These include the inability to recognize and comprehend the full significance of the information...";

(ii) Psychological Factors: (Continuing the above paragraph:) "...and certain psychological factors:

-- the difficulty of accepting a completely unexpected situation,

-- the fear of believing that the situation was as bad as the instruments suggested, and

-- a strong desire to focus on getting the reactor stable again rather than dwelling on the severity of the accident."

(iii) Procedural Factors: The control room crew can be overcome by complex procedures so that it cannot communicate conscientiously with outside support. The Kemeny Report (President's Commission 1979) cites a point during the hearings subsequent to the accident where the operators argued for more than half an hour about the appropriate action called for by a written procedure. Such problems arose repeatedly during the TMI accident. According to this report, these difficulties were often caused by written procedures that assumed either normal system status, near-normal system status, or at least a situation where the operators understand the system status. This is true for the European plans as well. None of these conditions held at TMI; it was often not clear how to follow a written procedure.

(iv) Incentive Factors: As noted before, the operators must detect an accident situation from indicators rising from the noise of normal operations--to ensure the best management of the accident and to leave most time for implementing any necessary countermeasures, that detection should be timely. From this perspective, accident detection can be treated as a classical signal detection problem, where the "trigger point" is the threshold value of the status indicators at which the operators decide to notify off-site experts or authorities. The rewards for correctly detecting an accident or correctly remaining silent when there is none are offset by the relative costs of missing (or delaying notification of) an actual accident (missed positive) or declaring an accident when in fact there is none (false alarm). Unfortunately, the rewards and punishments to the operator for false alarms, missed positives, and correct actions do not always match the social costs and benefits. For example, an operator who faces possible ridicule and diminished career prospects if he sounds a false alarm could set a higher accident-detection threshold than is socially desirable. He would be more apt to miss (or delay detection of) an actual accident than he should be. This problem is not unique to the field of nuclear safety. Any operator responsible for the lives of others, from an airline pilot to a ship captain, cannot be counted on to take the socially best action unless his personal incentives are made to correspond to the social costs and benefits of his decision.

Delays

The problem of delays in communication was first raised above as a consideration in decisions concerning the maintenance of routine availability of technical support personnel. In addition, accident-management communication must deal with the delays where they have not been removed from the system. The TMI accident showed that it is easy to underestimate the delay in communication. During discussion on this topic at a recent IIASA workshop (1980), it emerged that an important phone call in the Federal Republic of Germany emergency exercise took two minutes to complete. A representative of the US Nuclear Regulatory Commission responded that similar phone calls during the TMI incident often took forty-five minutes! The reason given was the receiving person typically refused to act on the message, but rather asked large numbers of questions to gain background information. The same person commented on the great deal of time it took to locate people, transport them to the site, then brief them fully on the current situation. Because the FRG drills did not include a confusing accident, where the plant status is not easily describable, in fact not sufficiently known, these long delays were not in evidence during the drills reported in the 1980 IIASA workshop session. This problem of preparing for a confusing accident will come up repeatedly, and will become a focus for our recommendations.

Since accident management often cannot afford to wait for the appropriate expert or desired calculation, the problem of delays in communication gives rise to the need to make decisions in the face of great uncertainty. Planning for decisionmaking under uncertainty is not adequately addressed in the emergency plans studied to date. The plans reviewed in Section III are oriented toward well-understood accidents, where decisions can readily be made because the current and future status of the system is well known. Such plans are not adequate preparation for operators making decisions in the confusion of an accident such as that at TMI.

Signal-to-Noise Ratio

Another difficulty with communications is brought about by the volume of messages passing back and forth in a confusing accident such as the one at TMI. The acknowledgement and retrievable storage of information can fully tax the mental resources of the operator team. In the welter of information, the important indicators can be lost. This gives rise to the need for a mechanism to screen the information before it reaches the decisionmakers. Several suggestions for the solution to this problem were presented in the previous section, where we discussed the lessons learned from TMI.

Limited Usefulness of Technical Support

It is tempting to assume that once technically excellent minds are on the job, uncertainty will be dispelled and the accident will be managed with full understanding. Unfortunately, the experience at TMI shows that even with extensive expert technical consultation over hours and days of deliberation, a great deal of uncertainty in system status persisted. Though it took only a phone conversation with a Babcock and Wilcox engineer to find out that a block valve should be closed, this discovery took place two hours and twenty minutes after the accident began--after extensive consultation with several technical sources. *Several key areas of misunderstanding or lack of understanding persisted for days at TMI, even with a veritable army of America's best technical minds assembled at the site.*

The Decisions Required

A great deal can be said about the problems of on-site, off-site communications networks in nuclear accident management; however, in keeping with the scope of this research project, this discussion is limited to the role the operator team should play in that network. The best way to structure the problem is to characterize the decisions required, then set out how the operator team should input into those decisions. In the case of nuclear accidents, the decisions made by government authorities include both the choice of which countermeasures to implement (shelter, evacuation, thyroid blockers, warning, no action) as well as the choice of where it should be implemented (radius, sector). Table 2 shows the applicability of these measures as proposed by international authorities (IAEA 1979). Risks and costs are associated with implementing a countermeasure whether or not a release occurs, just as there are risks for not implementing countermeasures if a release does occur. Thus, the decision to order a countermeasure involves a balancing of social and political risks and costs.

Key Agents in the Decision

The nature of the information problem becomes clear when the agents to the decision are listed:

1. Technical Experts: The technical experts have the best appreciation for the plant status, including the hazards involved in the current and possible future status of the plant. However, the technical experts have no social or legal authority to make the

social risk tradeoffs necessary for any decision invoking countermeasures.

2. Government Authorities: The government authorities have the legal power to make the social risk tradeoffs for countermeasure decisions. These tradeoffs may involve political factors and other considerations such as non-technical aspects of the weather. If it is a nice spring day, the political consequences of an unnecessary evacuation will be quite different from those consequences of evacuating on a freezing-blizzard day. Since government authorities are generally not technical astute, they cannot have the same appreciation of the hazard situation as technical experts.

Communication of Plant Status

In an earlier section, we discussed the problems of communicating with technical sources. In this section, we turn to one of the most critical areas of accident response, assessing and communicating the severity of the accident or the status of the plant.

It is usually assumed that an accident can be defined in terms of a release; the operator's duty is to assess the severity of this release and with this information the responsible authorities can order the appropriate countermeasures. The US Protection Action Guides (PAG), linking release to countermeasure, are given in Table 3.

It is important that neither the guides presented in this table nor those recommended by the FRG (see Table 4) would help an operator faced with the situation encountered at TMI, where a hydrogen bubble was discovered in the core. For some time, nobody could predict whether this bubble would or would not burn or explode, leading to a possible major release with no warning. It is unimportant that it was later calculated that the bubble could not have burned. The point is that at one time all that some accident management people knew was that there was a hyrdogen bubble which might cause a major release without warning. A PAG based on a projected dose was of little or no help to the decisionmakers.

This accident shows that countermeasure decisions may have to be made in the face of great uncertainty. The critical question which has not been addressed is how the operator can communicate this uncertainty. In the words of the President of General Public Utilities, the

Table 2. Applicability of Protective Measures.

Protective measure	Phase: Early	Phase: Intermediate	Phase: Late
Sheltering	**	*	-
Radioprotective prophylaxis	**	*	-
Control of access and egress	**	**	*
Evacuation	**	**	-
Personal protective methods	*	*	-
Decontamination of persons	*	*	*
Medical care	*	**	*
Diversion of food and water supplies	**	**	**
Use of stored animal feed	**	**	**
Decontamination of areas	-	*	**

** applicable and possibly essential

* applicable

\- not applicable or of limited application

NOTE: Although the protective measure of removing domestic animals in the food chain from pasture and putting them on stored animal feed is not an immediate protective measure beneficial to humans, nevertheless, if the situation warrants, the earlier the animals are put on stored feed the greater may be the dose savings at a later point when animal products begin to enter the food chain.

Source: IAEA

Table 3. Recommended U.S Protective Actions Guide to Reduce Whole Body and Thyroid Dose from Exposure to a Gaseous Plume

Projected Dose (Rem) to the Population	Recommended Actions[a]	Comments
Whole body <1 Thyroid <5	No planned protective actions.[b] State may issue an advisory to seek shelter and await further instructions. Monitor environmental radiation levels.	Previously recommended protective actions may be reconsidered or terminated.
Whole body 1 to <5 Thyroid 5 to <25	Seek shelter as a minimum. Consider evacuation. Evacuate unless constraints make it impractical. Monitor environmental radiation levels. Control access.	If constraints exist, special consideration should be given for evacuation of children and pregnant women.
Whole body 5 and above Thyroid 25 and above	Conduct mandatory evacuation. Monitor environmental radiation levels and adjust area for mandatory evacuation based on these levels. Control access.	Seeking shelter would b an alternative if evacuation were not immediately possible.
Projected Dose (Rem) to Emergency Team Workers		
Whole body 25 Thyroid 125	Control exposure of emergency team members to these levels except for lifesaving missions. (Appropriate controls for emergency workers, include time limitations, respirators, and stable iodine.)	Although respirators ar stable iodine should be used where effective tc control dose to emergency team workers, thyroid dose may not be a limiting factor for lifesaving missions.
Whole body 75	Control exposure of emergency team members performing lifesaving missions to this level. (Control of time of exposure will be most effective.)	

(a) These actions are recommended for planning purposes. Protective action decisions at the time of the incident must take existing conditions into consideration.

(b) At the time of the incident, officials may implement low-impact protective actions in keeping with the principle of maintaining radiation exposures as low as reasonably achievable.

Source: U.S. Environmental Protection Agency.

Table 4. Recommended FRG Emergency Reference Levels and Protective Action Levels. (Levels of Dose)

Whole body, Bone marrow, Gonads, Uterus	5 rem
Skin, Bone (Endosteal tissue)	30 rem
Hands and Feet (Skin included)	60 rem
Thyroid, any other organ or tissue	15 rem

The Radiation Protection Ordinance dated from 13 October 1976 specifies the following design basis accident levels of dose (dose commitment) to apply to members of the general population, which nowadays are considered as emergency reference levels too:

In case of an incident or accident, which causes these reference levels of dose or makes them imminent, a disaster alert shall be given.

Below these levels there is no need to implement immediate measures to protect the population itself.

Above the levels there are action levels belonging to certain actions.

It must be emphasized, that the appropriate protective actions cannot be decided solely on the basis of fixed action levels; it is also necessary to consider the situation, the probable development of the situation, the phase of the accident and the practicability and efficiency of instituting countermeasures at the given circumstances.

Source: IAEA.

owners of the Three Mile Island plant:

> In this regard it is my impression that the most important thing is for the plant, the management, the regulator, and civil authorites to pre-estalish a set of critical parameters which will be the basis for reportin plant status and assessment of potential for public impact. (Dieckamp 1979).

In the remainder of this section, we will be concerned with the development of the notion of a set of parameters which could be the basis for reporting an uncertain plant status.

A Suggestion for Improving Communications

Part of the philosophy of emergency procedure design and accident prevention should be based upon past experience. Though every effort should be made to prevent recurrence of past accidents, it would be irresponsible to acknowledge that not every failure which is *a postiori* obvious could have been obvious *a priori*. New regulations stemming from past experience tend to deal with a well-structured problem defined and revealed by the accident, rather than the ill-structured problem existing before the event.

Because the situation before the event is often ill-structured, a first priorty is to counteract the problem of information overload on the operator. For this purpose, accident management information could be ranked and screened so that only the most important and appropriate information gets to the operator team, with the rest of the information shunted to data recorders and support groups in different rooms. In part, these considerations should be dealt with by those working on instrumentation systems. In addition, it is important to rank and to screen accident-management information that is not collected via the instruments.

A second problem introduced above, and to which we turn our attention for the remainder of this section, is that of coping with a poorly structured and uncertain situation. How does the operator convey an uncertain plant status to outside authorities?

The Development of a Standard Language System

One possibility suggested by a growing school of thought on the use of probabilistic information, is to train the operator in the use of subjective probability. Ideally, the operator or technical experts could express their state of knowledge concerning plant or accident status in terms of a set of subjective probabilities. The government authorities could, in turn, be briefed on the use of these probabilities, specifically in how they translate into action. In this regard, one could imagine a table, such as Table 5, relating probabilistic numbers to countermeasures. This table should be contrasted with the language of the US PAG's (see Table 3).

Table 5. Probabilistic Information on Present and Future Dose Releases

time periods	1/2 hr.	1 hr.	2 hr.	4 hr.	8 hr.
Prob. max dose > 10R (%)	.5	1	1	5	1
prob. max dose > 1R (%)	1	5	5	10	5
max. possible counter measures:	shelter and KI	evac. to x_1 km	evac. to x_2 km	evac. to x_3 km	evac. to x_4 km

This scheme, simple enough on paper, would probably not work in an accident situation. There are two important reasons for this:

(i) in the midst of an accident, the operator team probably could not meaningfully set subjective probabilities; and

(ii) even with the help of a guideline, government authorities cannot be expected to understand and be comfortable enough with subjective probabilities to combine such information appropriately with social and political value information to come to an appropriate countermeasure decision.

Taking this idea a few steps further, this pre-determined language could have as a vocabulary, not probabilities, but simple key- words or colors ("condition red") or numbers. These key-words could be associated with, say, from three to ten standard paragraphs, denoted by $\{P_1, ..., P_n\}$ or simply $\{P\}$, with the higher index values denoting paragraphs describing more hazardous situations.

While in the following discussion the language will always be referred to as being used by the operator or operator-team, in a longer-term accident, the responsibility for determining the appropriate paragraph could shift to the ETSC.

Requirements, Aspects of the Standard Language

Ideally the Standard Language System (SLS) would induce the operator to move from very coarse aspects of system status to a particular paragraph. For this purpose, the mapping from system status to paragraph must be unambiguous. The operator could then be held liable if, for instance, he transmits a particular plant status, P_2, when it was unambiguously P_3, since post-accident hearings could reasonably determine that he should have used P_3. The SLS also relieves the operator of some of his responsibility, in that he can refer to the mapping guidelines; using the SLS, he is called upon to exercise his judgment less.

Ideally, the SLS would also induce the government authority to act upon the paragraph received with a particular countermeasure. Given the paragraph received and extenuating circumstances, the authority must feel that only one or two countermeasures could be justified in post-accident hearings. The authority is also relieved of some of its responsibility, since it can cite the paragraph given as partial justification of the decision.

Benefits of the Standard Language System

The above, however, call for the SLS to have an unambiguous mapping from system status to paragraph and a reasonably clear mapping from paragraph and extenuating circumstances to particular countermeasure. This raises the possibility of a more direct language, mapping straight from status to countermeasure. Yet an intermediate nature for the SLS is judged preferable to a more direct language, chiefly because it divides responsibility between the operator and the government authority in an advantageous way. This division of the intermediate SLS leaves the operator with a relatively technical judgement and thus less prone to bias his estimate in the light of potential non-technical consequences. Conversely, the government authority, left with a relatively non-technical judgment, is able to bring in other considerations (politics, weather), in a cleanly structured way.

The SLS allows the structured "pre-digestion" of very difficult judgements and decisions that could not be made well in the heat of an accident. The net effect would be to decrease *ad hoc* human judgments in accident management, replacing them with more carefully considered judgments.

The SLS would provide an appropriate avenue for openness, and so would help prevent the loss of credibility that so complicated the TMI accident. Finally, the SLS would build into the accident management system a pre-determined means of describing and reacting to a very uncertain plant status, both current and future.

Difficulties in Developing the Standard Language System

Some of the major difficulties encountered in the development of the SLS are as follows:

1. Operator Stress: The operator will be under severe stress and some distraction in the course of an accident, so the mapping from system parameters to paragraphs must be kept simple, and use only coarse system parameters.

2. Novel Accidents: No new accident is like any past accident; thus, the TMI accident was not expected. None of the pre-determined accident alarm levels was exceeded during the course of events. It follows that the mapping from system parameters to paragraphs must be kept general.

3. Size of Language Vocabulary: The choice of the number of paragraphs to include in the SLS involves a difficult balance: the greater the number of paragraphs, the more guidance given to the government authority. But at the number of paragraphs increases, the more difficult will be the operators task of choosing among them.

4. Phrases Used in the Paragraph: The wording of the paragraphs determines the relative difficulty of mapping from system parameters to paragraph versus mapping from paragraph to action. Paragraphs worded in system-status terms are easy for the operator to select, but are difficult for the authority to use. Alternatively, paragraphs worded in countermeasure terms are difficult for the operator to select, but are easy for the authority to use. Ideally, the paragraphs should be worded in terms of present and future hazard, capturing the information contained in Table 5.

5. Paragraph to Action Mapping: The guidelines for matching countermeasure action with system-status as set out in the paragraphs cannot be set by the technologists alone. The government authorities also have a responsibility to participate, since a mapping must involve social value judgments that only they can make. These guidelines should be periodically thought through with the relevant government authorities in the course of maintaining preparedness for an accident.

VI. PRINCIPLES FOR ASSISTING NUCLEAR ACCIDENT MANAGEMENT OPERATIONS

This section presents the basic principle points to be followed in planning for nuclear accident management that can be gleaned from the preceding sections. They are viewed from the perspective of the operator. The principle that underlies all the others is that all planning efforts should be directed toward reducing the information processing load carried by each person involved in managing an accident. A lesson learned from previous accidents is that there is a very large amount of information requiring rapid and appropriate response. The individual information processing load can be reduced substantially by two planning measures:

(i) by giving each person a clear and specific role within a well-understood information processing structure;

(ii) by anticipating as many accident management decisions as possible in the planning process.

Thus, real-time, *ad hoc* decision making can be reserved for unexpected features of the accident. These fundamentals form the basis for a further eight more specific principles. Because they are covered in more detail in previous sections, they are only identified and briefly explained here.

Structure

1. *Lines of Authority and responsibility should be clear and complete.*

There are several operations going on simultaneously in the course of a nuclear accident. In addition to immediate attention to the reactor, other operations include accident assessment and prediction, technical spport, considerations of offsite countermeasures, decisions on and execution of countermeasures, and information management and dissemination. The individual and the agency responsible for specific operations should be made clear in accident management plans.

2. *Lines of communication should be clear and complete.*

Information sources, dissemination links, and sinks should be clearly laid out, specifying who is responsible for what information where, to whom that information is to be delivered, with what screening, and with what training required.

Information Management

3 *Active information management should be imposed on all lines of communication.*

The pervasive problem in accident management is one of signal-to-noise ratio: picking the important facts from a welter of information. Planning for each line of communication, then, should include procedures for screening and ranking information, and chanellng it to non-distracted decision makers.

4. *Separable operations should be kept separate, in separate rooms, with different operations.*

There are distinct operations involved in accident management, as listed above. The onsite operations ca be categorized into reactor operations, technica back-up-overview, and administrative operations. Each of these should be handled by separate teams of people, separated from the others spatially, acoustically, and operationaly, with carefully screened lines of intercommunication.

Aids to Individuals in the Process

5. *Accident management staff should be selected to combine technical knowledge, plant familiarity and availability*

Because individuals possess ideal levels of all three qualities listed, teams of people for each operation must be selected to get the combination of qualities required.

6. *Operators and other decision makers should be offered appropriate incentives for decisions.*

Ordinary personal rewards, penalties for sounding false alarms, missing cues, or correctly responding may not correspond to the social costs and benefits involved. Such incentives should be adjusted, in ways very clear to the decision makers, to ensure that corrective measures correspond to the public interest. This principle extends to drills, where operators should be clearly and strongly rewarded for appropriate performances.

7. *Procedures should be transparent and unambiguous, even in accident situations.*

This principle is difficult to put into practice, because accidents can involve unanticipated system behavior. One solution to this problem is to have a set of unambiguous fall-back procedures for use in response to anomalous sets of signals.

Management Under Uncertainty

8. *Communications and procedures must be specifically designed to help people make decisions under extreme uncertainty*

In the course of a poorly understood accident, one of the key problems can be conveying the uncertain reactor system status to others, and making decisions in the face of the uncertainty. This problem can be overcome by the development of a Standard Language System (SLS) to describe the hazard. The SLS can include procedures for deciding on standard descriptions of the hazard on the basis of anomalous measures from a poorly understood reactor system. This allows the planning out of difficult decisions, easing the task of the real-time decision maker.

VI. CONCLUSIONS

In addition to the principles listed above, other general remarks ca be made here in smmary form.

Similarity of Accidents

A study of several non-nuclear accidents found that there are broad similarities in the structure and development of major accidents. This is a very important finding, as the key problem in planning for nuclear accidents is that they are extremely rare.

Information Management

A second conclusion is that information management plays a central role in accident management. The cues preceeding an accident rise out of a background of inconsequential fluctuations in performance. Their early identification, then, is a signal detection problem. Even after identification, the accident management problem can be characterized as an information processing problem: the attempt to react appropriately to a very large amount of information in a short time.

Planning to Deal with Uncertainty

The most basic and important conclusion arises frm a comparison of the accident at Three Mile Island in the US, and the plans for nuclear accidents in some European nations. Current plans do not appear to plan adequately for poorly understood, slowly developing accidents where there is a great deal of uncertainty about the current and future status of the system. This is in part due to the fact that it is extremely difficult to plan for a rare event, and to verify that the planning is adequate. Past accidents, seen through the lens of hindsight, are typically studied as a well-structured series of events. Future accidents, as represented in drills, are typically represented again in a well-structured manner. An actual future accident may well be ill-structured and poorly understood. That uncertainty led to great difficultes in communications and decision making.

Clearly, accident planing should help operators cope with uncertainty of the sort experienced at TMI. Yet a study of past US and some European plans finds that they have been based on the assumption that a serious accident would be initiated by a recognizable and distinct event that gives, at least, a confident and low bound to the maximum release in the near future. Accidents in those plans are characterized in terms of doses, countermeasures are then dictated at particular dose levels. The plans do not seem resilient to the confusion and uncertainty of a poorly understood accident. Past accidents show that individuals have difficulties in recognizing, comprehending, and dealng with an accident, especially so when a great deal of uncertainty is involved. A standardized language, all designed to help cope with uncertainty, is required. That aspect of nuclear accident management does not appear to be adequately addressed in the plans studied.

General Summary

It is possible to draw together certain conclusions which may be useful in the eventual formulation of recommendations. To revert to the illustration of accidents laid out in the introduction these latter would represent some of the "new norms" of Phase VI (see Figure 1). In summary, the condusions are:

1. Accidents, nuclear or other, can be argued to have common characteristics and structure.

2. This structure allows certain comparative observations to be made, particularly with respect to communications.

3. Effective, though appropriately limited, communications are vital to the handling of accident situations.

4. The efficiency of the appropriate communications depends upon a complex of factors--institutional and administrative, social and psychological.

5. Recognition that accidents may occur outside the preconceived band of possible characteristics and structures is necessary.

6. Use may be made of the TMI accident experience to improve existing European contingency plans in certain areas.

REFERENCES

Baas, J.L., and B.F.M. Bosnjakovic. 1980. "Nuclear Accident Response and Population Protection in the Netherlands: Philosophy, Solutions and Problems." Paper presented at the TMI Workshop, Laxenburg, Austria. January.

Bignell, Victor, Geoff Peters, and Christopher Pym. 1977. *Catastrophic Failures.* Great Britain: The Open University Press.

Dieckamp, H. 1979. "The Accident at Three Mile Island: The Owner/Operator's Assessment." Paper presented at Atomic Industry Forum Conference, November.

International Atomic Energy Agency (IAEA). 1979. *Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities.* IAEA-TECDOC-225, Vienna: IAEA.

Matthews, R.R., and R.B. Pepper. 1980 "Emergency Plans and Procedures at U.K. Nuclear Power Stations." Paper presented at the TMI Workshop, Laxenburg, Austria, January.

Otway, H.J., and R. Misenta. 1980. "The Determinants of Operator Preparedness for Emergency Situations in Nuclear Power Plants." Paper presented at the TMI Workshop, Laxenburg, Austria, January.

President's Commission. 1979. *The Accident at Three Mile Island.* John G. Kemeny, Chairman, Washington, D.C.

Rogovin, Mitchell, Director. 1979. *Three Mile Island: A Report to the Commissioners and to the Public.* Volume I, Washington, D.C.: Nuclear Regulatory Commission Special Inquiry Group.

Three Mile Island Workshop. 1980. *Summary of Discussions.* Laxenburg, Austria: International Institute for Applied Systems Analysis (IIASA).

Turner, Barry A. 1978. *Man-Made Disasters.* London: Wykeham Publications, Ltd.

United States Nuclear Regulatory Commission (US NRC). 1979a. "Investigation into the March 28, 1979, Three Mile Island Accident by Office of Inspection and Enforcement." Investigative Report No. 50-321/79-10. NUREG-0600. Washington, D.C., August.

US NRC. 1979b. "Final Report: TMI-2 Lessons Learned Task Force." NUREG-0585. Washington, D.C., October.

US NRC. 1979c. "Status Report and Short-Term Recommendations: TMI-2 Lessons Learned Task Force." NUREG-0578. Washington, D.C., July.

van Gadow, A. 1980. *Emergency Planning in the Vicinity of Nuclear Installations.*