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ORNL--5941

DE84 013577

Energy Division

PROTECTIVE ACTIONS AS A FACTOR IN POWER REACTOR SITING

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Date Published - June 1984

Prepared for the
U. S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555
under
Interagency Agreement DOE 40-543-75
NRC FIN No. A-9043

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for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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EXECUTIVE SUMMARY

This report explores the relationship between nuclear power plant site characteristics, emergency preparedness, and emergency response. It examines how the feasibility and efficiency of protective actions taken by the public (measures to prevent or reduce radiation exposure) may be affected by siting practices.

A number of protective actions were considered, e.g., evacuation, sheltering, ventilation control, expedient air filters, and pharmaceutical prophylaxis. Impediments resulting from site characteristics to the implementation of these measures were identified. The ease of implementation and the effectiveness, as compared to no use of protective actions, were examined from a siting perspective. The potential effectiveness of some actions, particularly evacuation and shelter, may be affected by site-specific factors.

This evaluation concentrated on measures to reduce potential short-range and short-term effects of a serious reactor accident. Deaths or injuries resulting from acute radiation exposure have induction thresholds, i.e., substantial radiation exposure is necessary in order to induce these effects. Preventing such substantial exposure can eliminate deaths or injuries. These are also predominately short-range consequences. Other potential effects, such as latent cancer or property damage, have no, or very low, induction thresholds. These other effects also increase with population and are most pronounced further away from the plant, outside the area in which immediate evacuation might be expected, predetermined, easily implemented, or effective. Sheltering and expedient respiratory protection would be effective and feasible in areas further away from the reactor site. A more leisurely evacuation of a limited area away from the plant because of ground contamination would also be feasible. These short- and long-range perspectives are important.

Evaluation of the effectiveness of protective actions requires assumptions about the nature of the radioactive release. Accident

source terms used for this purpose were developed for the Reactor Safety Study or derived from those numbers. These source terms are now thought to be perhaps two to five times too high. Reductions in the source term would not only reduce the expected consequences of the release, but could also reduce the area in which prompt protective actions are appropriate.

Having defined the limits of this investigation, the authors tried to identify the problems that might hinder the effectiveness of protective actions. Solutions to these problems were divided into siting questions and emergency planning considerations.

Accident consequence calculations indicate that prompt evacuation of areas near the plant is the most effective way of reducing acute deaths and injuries. A prompt evacuation has these two components: early notification and expeditious movement.

Early notification can reduce the delay in leaving the area after the release occurs. It would be best if the people were notified well in advance of an actual major release. This delay time is dependent on such things as operator recognition of the emergency conditions, predetermined action levels for recommending evacuation, early and prompt notification of the public, and the motivation of the public to respond. Although peculiarities of the plant site can complicate notification procedures, notification is an emergency planning problem, not a siting issue.

Expeditious movement out of the threatened area is certainly important, given an actual or imminent major accidental release of a large amount of radioactivity to the atmosphere. Expeditious does not necessarily imply high speed travel. Using the existing conservative source terms and assuming a 1-h warning before a major release, a 1-h delay in leaving, and radial movement at 10 mph, theoretical calculations suggest no acute radiation fatalities would be expected among those evacuating, even for the worst source term postulated. Movement at higher speeds would provide little extra benefit. With early warning and clear directions, the radiation dose could be avoided by persons walking in a crosswind direction.

Impediments to evacuation can affect the expeditious movement away from the reactor. Some of these impediments may be siting issues. A number of site-specific factors, such as geography, transportation systems, frequent bad weather conditions, institutional populations, and political considerations can make planning for effective evacuation a very complex problem. If alternative or corrective measures cannot be identified, inability to evacuate promptly the area around a proposed plant site could be sufficient reason to prevent siting there. Based on the historical evidence, it is extremely difficult to think of such a situation where both evacuation and alternative measures are impossible.

The character, kind, and availability of shelter in an area could vary from one reactor site to another. More shelters and higher-quality shelters are generally available in congested areas than in sparsely populated areas. Restricting nuclear plant sites to urban areas in order to have better shelters conflicts with the practice of reducing risk by locating plants away from large population centers. As an emergency planning measure, the best available shelters near a site could be identified for possible use in the event of an accidental release from a reactor. Locally-initiated emergency planning measures could require that shelter be available or be added to new construction through zoning restrictions. As in all emergency planning, the cost/benefit ratio in further reducing the small risk from a reactor accident by moving people to better shelter must be considered. Increased risk incurred by the movement would also have to be examined.

Siting restrictions on the number of people living in the vicinity of a power reactor will limit the risk of off-site radiological consequences in the event of a large atmospheric release. Limits on population centers can reduce the potential peak consequences of an accident. But reducing the number of people cannot assure that these people can evacuate effectively or find adequate shelter. In fact, there is no agreement on the relationship between population density and evacuation time (one study showed an inverse relationship). Restriction of the total population outside the emergency planning zone could reduce the potential for latent cancer induction and property damage after a serious accident, but this could not totally avoid the small increase in cancer risk that is assumed to occur with any increase in radiation exposure.

What then can be said about siting policy and its relationship to protective actions? Most of the issues discussed have been at least implicitly considered in previous siting decisions. Siting regulations can restrict the number of people living near a plant and thus, reduce the consequences of an accident. The variability in site-specific factors influencing protective actions make it difficult to develop specific regulatory guidance that is universally applicable.

Emergency planning has an important role. Emergency plans are site-specific. They can address the identified impediments in flexible, creative ways, such as developing alternative procedures (e.g., provisions for very early warnings to the people) or recommendations for supplementary protective actions. The adequacy of these proposed solutions could strongly influence any licensing decision because each plant must have an approved plan before an operating license can be issued. By concentrating on the area up to 10 miles from the site, siting regulations and emergency plans, combined, provide the potential to avoid most, or possibly all, early fatalities and injuries. Reevaluation of the current NRC accident source terms may have a significant effect on the area in which siting and emergency planning regulation is warranted.

ACKNOWLEDGMENTS

The authors are grateful to D. C. Aldrich and D. J. Alpert, Sandia National Laboratories; C. E. Kent, Tennessee Valley Authority; and J. A. Martin, Jr., U.S. National Nuclear Regulatory Commission for sharing their information and opinions on emergency planning. The assistance of A. P. Hull, Brookhaven National Laboratory, and R. N. Thurmer, Oak Ridge National Laboratory, in locating and obtaining reference material and of J. A. Coleman, N. L. Elrod, C. J. McCoy, and N. W. Watlington, Oak Ridge National Laboratory, in typing the manuscript is also appreciated.

PROTECTIVE ACTIONS AS A FACTOR IN POWER REACTOR SITING

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ABSTRACT

This report examines the relationship between a power reactor site and the ease of implementing protective actions (emergency measures to reduce the radiation exposure to the public in the unlikely event of a serious accident). Limiting population density around a reactor lowers the number of people at risk but cannot assure that all protective actions are possible for those who reside near the reactor. While some protective measures can always be taken (i.e., expedient respiratory protection, sheltering), the ability to evacuate the area or find adequate shelter may depend on the characteristics of the area near the reactor site. Generic siting restrictions designed to identify and eliminate these site-specific constraints would be difficult to formulate. The authors suggest identifying possible impediments to protective actions at a proposed reactor site and addressing these problems in the emergency plans.

1. INTRODUCTION

1.1 APPROACH TO REACTOR SAFETY

To minimize the risk to the public from a severe accident at a power reactor, three independent but related types of actions have been taken. Nuclear plants are designed with many redundant safety systems to insure that the public will not be harmed, even in the unlikely event of a serious accident. Siting regulations and regulatory guides encourage the location of plants on sites with appropriate physical characteristics and with adequate separation from population centers and sites supporting hazardous activities. Emergency response plans are the final defense against the consequences of a radioactive release during a severe reactor accident.

1.2 PROTECTIVE ACTIONS, EMERGENCY PLANNING, AND SITING

1.2.1 Role of Protective Actions

A protective action or a protective measure is an emergency response designed to avoid or mitigate the deleterious effects of a hazard. Protective actions, in the event of a reactor accident, would be directed toward lowering or preventing the radiation exposure to the public that might be expected from a large release. Site-specific characteristics of a reactor site and the surrounding area can make some protective measures more difficult to implement than others.

Because protective actions are the final defense, they are seldom utilized in response to reactor accidents. The safety record of the commercial nuclear industry is such that protective actions have never been ordered for the general public because of a reactor accident. The most serious commercial nuclear accident, the accident at Three Mile Island in 1979, did, however, result in an advisory for children and pregnant women to leave the area near the reactor.[1]

1.2.2 Role of Emergency Planning

The relationships between protective actions, emergency planning, and siting are often confused. The role of emergency planning is to achieve and maintain a level of preparedness so that essential and desirable tasks can be performed more effectively during an emergency. Emergency plans for reactor accidents may include procedures for facilitating protective actions or for deciding whether or not to recommend that such actions be taken. These plans may also address site-specific problems that could impede the implementation of protective actions. The planning process establishes rapid notification procedures and encourages cooperation among the various organizations and groups involved in responding to the emergency. The importance of planning has been recognized in the regulatory process; the adequacy of licensee, state, and local emergency plans will determine whether the reactor will receive or maintain its operating license.[2]

1.2.3 Role of Siting

Reactor siting criteria based on population are designed to limit the public risk from a severe reactor accident by triggering more extensive review of alternate sites when the surrounding population density and distribution exceed certain guidelines at the proposed site. These "trip levels" of population densities, indicating that more review is required, provide a means for controlling the maximum possible consequences. Siting regulations also discourage the location of plants near hazardous activities and require appropriate and geologic conditions for power plants.

1.3 POWER REACTOR SITING CRITERIA

1.3.1 Present Criteria

Current siting regulations[3] require that nuclear generating facilities be surrounded by an exclusion zone, where residential land use is prohibited, and a low population zone (LPZ). These zones are defined so that individuals located at the outer boundaries would receive no more than a specified radiation dose in the event of a "design basis" accident.[4] This means that precise exclusion distances and LPZ boundaries are determined on a site-specific basis, because the expected radiation dose from any given accident depends on both the location of the exposed individual, the size of the reactor, the severity of the accident, and the safety features designed into the facility. By "strengthening" plant design to reduce the expected release of radiation accompanying the design basis accident, the size of the exclusion area and low population zone can be reduced. In practice, the minimum distance from a nuclear plant to the exclusion area boundary ranges from 0.1 to 0.6 mile, with an average distance of about 0.4 mile. The LPZ is usually circular with a typical radius of 2 to 3 miles.[4] The relationship of these zones is shown in Fig. 1.1.

Present siting criteria limit the proximity of an acceptable power plant site to population centers. The distance to the nearest population center of more than 25,000 residents must be at least one and one third times the distance from the plant to the LPZ outer boundary. Where very large cities are involved, an unspecified "greater distance" may be required.[3]

The regulations do not ignore protective actions. A reasonable probability that appropriate protective measures could be taken in behalf of residents of the LPZ in the event of a serious accident is required.[3] The evaluation of the effectiveness of protective measures has, in the past, focused upon the ability to evacuate the LPZ in a timely fashion.[4]

In several instances since the passage of the siting regulations described above, applicants have attempted to site plants in higher-than-normal population settings by strengthening the safety considerations in the plant design. In the early 1970's, in order to prevent increased movement in this direction, ways to specify population constraints in the area surrounding nuclear facilities were investigated. This effort led to the development in 1974 of Regulatory Guide 4.7, General Environmental Site Suitability Criteria. This document[5] suggests numerical guidelines for the acceptable average population density of the area within 30 miles of a site; exceeding these limits would require that special attention be given to alternative sites with lower population densities.

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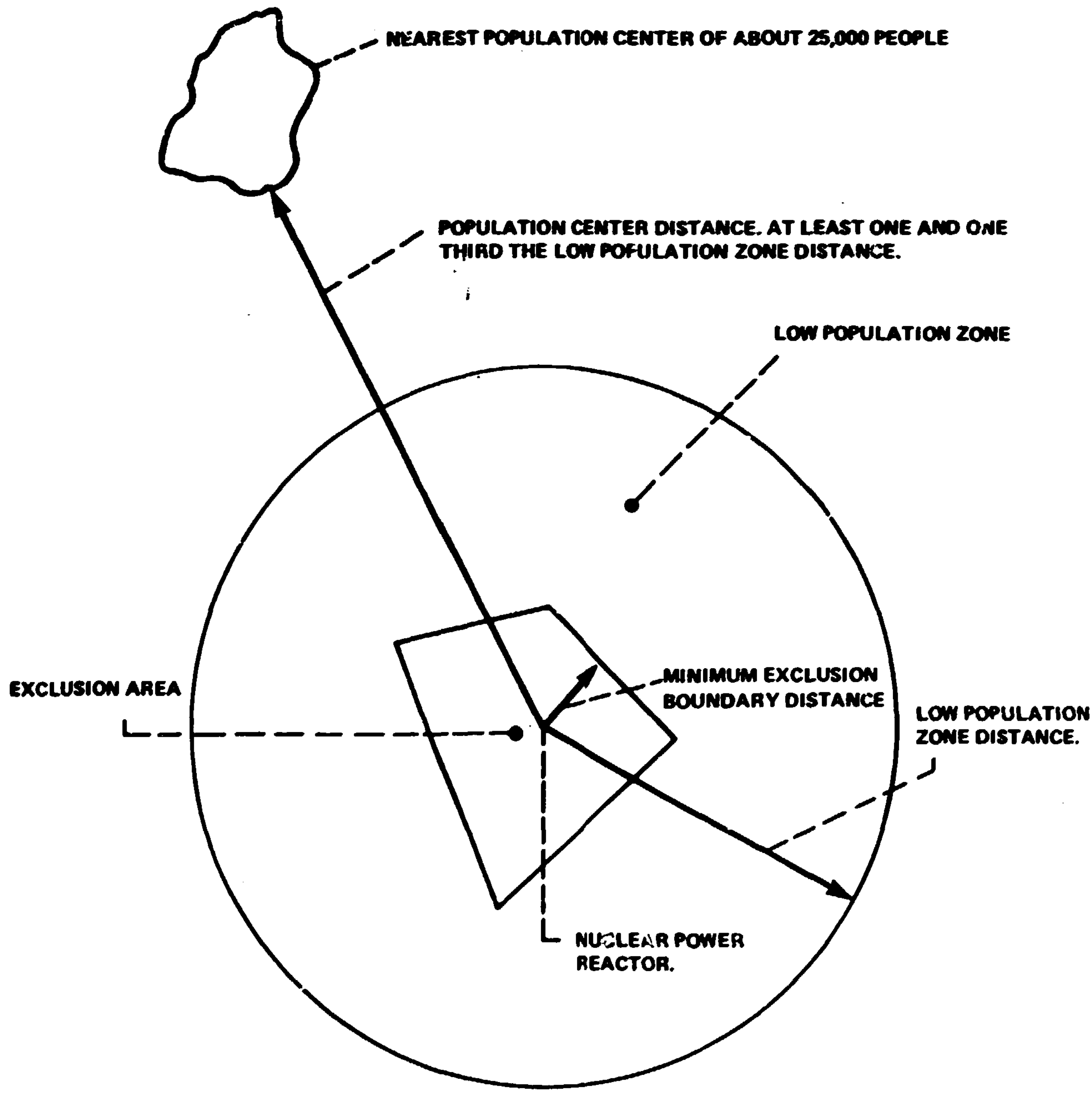

Fig. 1.1 Relationship of areas and distances established in current siting criteria.

Source: Demographic Statistics Pertaining to Nuclear Power Reactor Sites, NUREG-0348, U.S. Nuclear Regulatory Commission, Washington, DC, Oct. 1979.

In 1978, the NRC formed a task force to develop a general policy statement for nuclear power plant siting. The Report of the Siting Policy Task Force, NUREG-0625, was issued for comment in August, 1979. In June, 1980, the Congress directed the NRC to complete the development of reactor siting criteria by specifying criteria for maximum population density and distribution that are independent of the differences between plants.

1.3.2 Recommendation of the Siting Policy Task Force

The NRC's Siting Policy Task Force established three basic goals to guide the subsequent development of their siting recommendations. These goals were as follows:

1) To strengthen siting as a factor in defense in depth by establishing requirements for site approval that are independent of plant design considerations;

2) To take into consideration in siting the risk associated with accidents beyond the design basis (Class 9) by establishing population density and distribution criteria;

3) To require that sites selected will minimize the risk from energy generation.[4]

The third goal was tempered by the consideration that "siting requirements should be stringent enough to limit the residual risk of reactor operation but not so stringent as to eliminate the nuclear option from large regions of the country."[4]

The recommendations of the Task Force included establishing a fixed exclusion distance and an emergency planning zone (EPZ) to replace the LPZ[4]. The EPZ would extend about 10 miles in all directions from the nuclear plant and be designated so as to provide reasonable assurance that the residents of the area could evacuate promptly in the event of an accident. Limits on population density and distribution in the EPZ would be established. Population density up to about 30 miles from the reactor (depending on the power level of the reactor) would also be evaluated.

1.4 PUBLIC RESPONSE IN EMERGENCIES

In emergencies resulting from accidents at commercial nuclear power plants, can the public be expected to take protective actions under what are probably once-in-a-lifetime conditions? Because there is little experience with reactor accidents that threaten the offsite population, the behavior of people during natural disasters was examined to see how people might behave when threatened. Sociological studies[6] have shown that people are capable and willing to help themselves and others. The threatened community is seldom sliding into social chaos or in need of massive outside guidance and help. The greatest need is accurate and timely motivating information. Actions will be based on the available information and may be initiated well before any authority gives instructions, depending on the level of perception of the threat. Internal coordination of the active community forces is more important than direction from outside the community.

A nuclear power plant accident would be different from a natural disaster in some ways. The perception of the hazard may be greatly distorted by the political controversy surrounding nuclear power and the lack of first-hand individual experience with similar events. The recovery period from a major reactor accident might be longer than that from most natural disasters because of environmental contamination and the necessity of limiting access to the affected area, but this is not an immediate consideration. Outside resources may be required to a larger degree than in some non-nuclear emergencies, and the coordination problems could also be more difficult.[7]

The need for public information about threats from non-nuclear hazards is descibed by kreps as follows:

> There are intense pressures from the public for immediate information about victims, secondary threats, and emergency needs and activities following diasters. In effect, people seek to reduce uncertainty about the event, its consequences, and the appropriate personal actions to be taken.[7]

This need would be even greater in a radiological emergency because of the lack of public understanding of the threat and the lack of experience with appropriate responses. In the case of evacuation, "there is no reason to believe that because the disaster agent is radiation rather than some other agent, that it, in itself, will provide sufficient motivation to leave."[8] The problem is generally not panic flight, but getting people to move at all.[9] Prompt, accurate descriptions of the threat, the expected consequences, and recommended protective actions would be necessary.

Most protective actions are not unusual actions and can be initiated at short notice when the people are convinced of the value of the effort. As in other emergencies, people would "generally take effective action to protect themselves, their families, and others."[7]

1.5 SCOPE OF REPORT

This report will focus upon the potential effectiveness of various emergency responses in preventing the acute radiation-induced deaths and injuries from a serious reactor accident. Long-term effects such as latent cancer induction are only dealt with briefly. Site characteristics, as well as population demographics, that influence the feasibility of protective actions will be identified.

The question of "feasibility" requires some clarification. Some type of protective action is always assumed to be possible, but all mitigating actions are not equal. Some protective actions would be more effective than others, some would be more difficult to implement, and, given a particular situation, some would be more appropriate. The feasibility of protective actions, as used here, means that appropriate and effective mitigation is possible.

Protective actions, although suggested by the circumstances, may not always have the desired effect. A change in meteorologic conditions or release time could change the area of potential exposure. This change might result in people moving to a contaminated area from one later found to be unaffected by the release. These would be rare occurrences. While changes in recommendations may be occasionally warranted, most of the effort here is devoted to the expected situation.

As the interaction of site characteristics and protective actions is demonstrated, attention is paid not only to the effect of existing site-specific conditions but also to possible implications of new siting restrictions. Whether siting restrictions can improve feasibility of protective actions is one question to be examined.

2. PROTECTIVE ACTIONS AND SITING CONSIDERATIONS

2.1 TYPES OF PROTECTIVE ACTIONS

Protective actions available to the general public can provide increased security against the health and safety consequences of radioactive releases from reactor accidents. This chapter will discuss the following protective actions and identify the ways in which siting decisions could improve or limit their effectiveness:

(1) evacuation,
(2) sheltering,
(3) ventilation control,
(4) expedient respiratory protection, and
(5) pharmaceutical prophylaxis.

Radiation from a nuclear power plant accident can pose a threat to public safety in several ways. External radiation, whether from radionuclides in the plume released from the reactor or from radioactive contamination deposited on environmental surfaces, can contribute to the population exposure. Radioactive material can be inhaled from the plume or from deposited material that becomes resuspended in the air. Contamination of food and water sources can lead to ingestion of radionuclides and subsequent internal radiation exposure. Some protective actions can be effective against all these exposure mechanisms, while others would be specific to only one threat.

Protective actions can also be distinguished by the time frame in which they would be appropriate. Some mitigation measures may be undertaken as part of the recovery after a crisis. These include such things as providing uncontaminated food and water, decontamination of food, water, and property, and interdiction of use of an area until it is decontaminated or until the contamination has decayed to an acceptable level. Because these actions would be taken after the status of the radiation problem is known and would be concentrated on reducing the longer-term economic and social consequences as well as lowering chronic radiation exposure, they will not be discussed further. The ease with which long-term recovery can be accomplished may vary from site to site, but this report will concentrate on protective measures that must be taken earlier in an accident sequence to reduce acute radiation exposure to the people in the area surrounding the reactor. More detailed information on all the actions discussed briefly here will be found in Appendix A.

Evacuation -- where the threatened population leaves the danger area -- is one of the prime responses considered for a major nuclear reactor accident. Although more disruptive and harder to implement then sheltering in place, evacuation can protect against all the mechanisms of radiation exposure. The key to the effectiveness of evacuation is a prompt response. For complete protection the population at risk should leave the threatened area before radioactive material released from the reactor arrives.

Sheltering involves using the radiation shielding potential of existing buildings by entering and remaining in such structures during and after the passage of a cloud of released radioactive material.[10] It may include sheltering in place (i.e., people remain indoors at their present location or move inside the nearest available structures) as well as preferential sheltering (i.e., people move into nearby buildings that offer more effective radiation protection than those in which they are located). Sheltering may be followed by relocation, when the residents leave the area after the passage of a cloud to limit exposure to radioactive ground contamination. Recommending shelter may also be an initial step to get people to go indoors near radios, televisions, etc., before other protective measures are recommended.

Ventilation control is usually combined with sheltering. As a minimum, closing doors and windows and shutting down mechanical ventilating equipment will reduce the inhaled dose to those in the shelter. More elaborate efforts to reduce infiltration by plugging cracks or deliberately ventilating the shelter when the radioactive cloud has passed can provide further dose reduction.

Expedient filters held or secured over the nose and mouth can remove radioactive particles from the air to prevent their being inhaled.

These filters could be improvised from items such as handkerchiefs or towels.[11,12,13] Use of these devices could enhance the protection of sheltering or reduce the inhaled dose if radioactive material arrives before evacuation is complete.

Pharmaceutical prophylaxis differs from the other measures in that it ameliorates the effects of the exposure instead of preventing it. A chemical is used to block the effect of the exposure or to hasten the elimination of a radioactive contaminant from the body. Most of these chemicals are experimental or are used only in cases of severe overexposure,[14,15] but one compound, potassium iodide, has been approved for use by the general public. If taken before or simultaneous with inhalation of radioiodine, it will prevent most of the radioactive iodine from concentrating in some parts of the body, particularly in the thyroid.

Although protective actions may be broken into different types, they would seldom be used independently. Several types of actions may be chosen, with different measures suggested for different segments of the population at different times, or combinations of actions may be recommended simultaneously.

Siting criteria that limit the density and distribution of the population around the proposed reactor may have an impact on protective actions. Because these siting criteria reduce the number of people at risk from a power reactor accident, there are fewer people for whom protective actions would probably be necessary, and a less complex emergency plan might be adequate. Although perhaps not true in all cases, increased population density is thought to have a negative effect on emergency planning: "There is a linkage between the criterion of distance-number of people and that of emergency plan feasibility. Emergency planning becomes less feasible as the number of people involved increases."[16]

2.2 THE INTERACTION OF SITING AND PROTECTIVE ACTIONS

2.2.1 Time Components of Protective Actions

The effective use of protective actions in an actual response would involve a series of steps from the decision to implement to the completion of the action. For example, Urbanik et al.[17] have divided evacuation into five major steps: (1) decision, (2) notification, (3) preparation, (4) response, and (5) confirmation. The time required for each of the first four steps affects the time in which an evacuation can be carried out. "Decision time" refers to the time that elapses from the recognition of an emergency until the decision to recommend evacuation is made by an appropriate authority. "Notification time" is the time required to inform everyone in the affected area. "Preparation time" is the time required for the people to get ready to move. Finally, "response time" is the time necessary to travel out of the area. "Confirmation time," the time to verify the evacuation, would occur after the movement and should not delay the response.[17]

This division of steps applies in some degree to all protective actions. The length of the time components may vary with the action. The time required for some steps (e.g., response or confirmation) is more dependent on siting considerations. Some, such as notification time, may be similar for all the protective measures discussed. This phase will be discussed separately. A crucial time segment, the time for the utility to notify the local authorities of the emergency, may influence the protective action recommended, but this delay should be minimized through the utility emergency plans.

2.2.2 Sheltering

Description and Use. Sheltering may be the first protective action recommended in a radiological emergency. Sheltering in place would require minimal preparation or response time because the residents of the threatened area would be going indoors or remaining indoors where they are. Some degree of protection, depending on the quality of the shelter, is achieved against external exposure to penetrating radiation as the radioactive cloud passes and from radionuclides deposited on the ground and other surfaces after the cloud has passed, and exposure due to the inhalation of radionuclides.[18] Taking shelter will also prevent skin burns from beta particles emitted by the contamination.

The decision to recommend sheltering may be a relatively easy one to make because no great disruption in the daily routine would occur; thus, the decision time could be quite brief. With even a relatively small release, sheltering might be recommended in accordance with the accepted health physics practice of keeping radiation doses as low as reasonably achievable to reduce any long-term effects.

The notification time for sheltering may be similar to that for evacuating, and the response time for in-place sheltering should be very short. Taking shelter immediately would be an excellent preliminary step, providing some protection against external and inhaled radioactivity while placing oneself near radios and televisions in case other protective measures are recommended later. Sheltering might be followed by evacuation of an area before or after the passage of a radioactive cloud.

The effectiveness of taking shelter depends on the quality of the shelter and the timing of sheltering relative to the release. The quality of shelter will depend on the structures near the plant site. For example, basements and large commercial buildings will generally provide more protection against radiation than wood-frame structures[19] (see Appendix A). The number of larger commercial buildings is probably higher in areas of higher population density. When both the number of brick houses or houses with basements are small, the degree of protection achieved by sheltering in private residences during a serious radiological emergency may be less, but sheltering would still reduce the expected exposure.

Quality of shelter could be enhanced by preferential sheltering, i.e., sheltering in selected structures that provide better protection, but the time to effect sheltering would increase due to the extra preparation and travel time needed for the move. The distances traveled may not be as great as in an evacuation, and some people could walk to shelter. But travel, even over short distances, may introduce some problems to be discussed in regard to evacuation. Furthermore, if the accident were severe enough to warrant preferential sheltering, evacuation might be a more effective choice.

The short implementation time is an important factor in effective sheltering, as the dose reduction provided by the protective action decreases almost linearly with increased outside exposure time. Continued exposure to ground contamination after the passage of a cloud may, in a relatively short time, result in a dose larger than that from exposure to the radioactive cloud.[20]

The best use of shelter, other than as a temporary measure before other actions are recommended, is as an alternative to evacuation in situations where evacuation cannot be completed before the radioactive material arrives and when the duration of the release is short. Closer examination of the tradeoffs between sheltering and evacuation are necessary when the contamination arrives quickly and the release is prolonged.

Consequence calculations using existing source terms show that sheltering could be as effective as evacuation with relatively short delay times in the area 5-10 miles from the reactor if basements were abundant and exposure to the ground contamination were brief.[21] More recent work[22] confirms the effectiveness of sheltering (in areas with many basements) at this distance. Beyond 10 miles, both sheltering (even in areas with few basements) and evacuation are about equally effective in preventing early fatalities and injuries.[22] An informed choice of protective measures or a combination of protective measures requires knowing something about the nature and quality of the shelter available.

The Swiss rely on shelter (to be followed by later evacuation in extreme cases) and a fast alarm system to protect the densely populated areas around their nuclear power plants. A crucial factor in this decision is the knowledge that 80-90% of the people will have access to excellent fallout shelters and the remainder can be accommodated in basements or cellars.[23]

Siting Factors. The ability to take shelter is not influenced by reactor siting criteria. The type of shelter available is a site-specific factor that can be considered in developing emergency response plans. Knowledge of the quality of existing shelters may influence the choice between sheltering and evacuation.

Sparsely populated areas have fewer people to protect, but they are also likely to have fewer office and industrial buildings and fewer public fallout shelters that could be used as preferential sheltering sites. Regulations to limit power reactor sites to areas with abundant basements, such as the Northeast, or to urban areas with many large structures in order to improve the quality of available shelters would be in conflict with the preference for areas of low-population density.

Generic requirements are probably not worthwhile here in view of the preference for rapid evacuation if possible. Information on the quality of shelter available might be needed by those preparing emergency plans or those making protective action recommendations when evacuation would be difficult. Locating and planning to use good shelters for some people might be an appropriate emergency planning response to a site-specific evacuation constraint.

2.2.3 Evacuation

Description and Use. Evacuations, for a variety of reasons, occur frequently in the United States. A sample of newspaper reports from 1977 showed that evacuations of several hundred to a few thousand persons occurred at least once every two weeks. It is a procedure that many police, fire, and civil defense personnel have initiated in non-nuclear emergencies,[24] often as a precautionary measure. Evacuation as a protective measure in a nuclear emergency has received much attention. When implemented and completed before the arrival of radioactive material from the reactor, it can be completely successful in preventing exposure from external radiation and inhaled radionuclides. A critical factor in the evacuation in a radiological emergency is timing. Minimizing the delay before evacuation and facilitating the movement out of the area are the keys to effective evacuation. When significant releases of radioactive material are expected or occur and evacuation can be completed before the radioactive materials reach the residents, evacuation is the protective action of choice.

Projections of accident consequences show that evacuation to a safe area with delay times of 1 h or less would always be the most effective measure for reducing the early health effects from a serious accident. Calculations using the CRAC2 computer code[25] indicate that evacuation at 10 mph (with 1-h warning and 1-h delay) is as effective in preventing early deaths and injuries as excluding everyone from a 10-mile radius around the reactor.[26] Near the reactor, evacuation (even if the delay time is longer) may be the most effective measure, although the delay would increase the expected consequences from the accident. Evacuation may be preferable to sheltering in the area 5-10 miles from a reactor if the available shelter quality is poor,[21] but the advantages of evacuation might be very small in most cases.

Siting Factors. Prompt evacuation may be the protective action that has its success most dependent on siting considerations. There are a number of site-specific factors that can affect the amount of time required to evacuate an area in the event of a radiological emergency. Five such factors of major importance are (1) population distribution, (2) transportation and geographic barriers, (3) meteorologic conditions, (4) the presence of non-mobile and institutional populations, and (5) multiple political entities. For the most part, discussion of the effects of site factors will center on the response (travel) component of the evacuation process, but any potential impacts to the decision, notification, or preparation components will also be discussed.

Presently there is no agreement on the overall relationship between population distribution and the evacuation time. A 1974 study[8] of 64 non-nuclear evacuations carried out over the preceding 13 years found evacuation speed to be independent of the total number of evacuees and further, found an inverse relationship between population density and evacuation time. The appropriateness of this study for projecting nuclear related evacuation times has been questioned on the grounds that the data do not disaggregate notification, preparation, and response times. The median area evacuated in the cases studied was many times smaller than the area that could be affected by a nuclear emergency, indicating that the results may be more appropriate to smaller evacuations.

A recent NRC analysis[27] of projected evacuation times for 52 separate nuclear power facilities found no correlation between total population and evacuation time,* but it did find a fairly strong positive correlation between evacuation time and population density for the permanent area population. High density sectors were estimated to require a significantly greater travel time than would sectors that were more sparsely populated. For the transient population, on the other hand, response time was significantly less for the high density sectors. These time estimates are based on a variety of methodologies and assumptions, and there are no empirical data on evacuations prompted by nuclear power plant accidents to provide verification, so that any conclusions drawn at this point must be considered tentative. This indication that travel times during evacuation are shorter in less densely populated areas would speak for the wisdom of limiting population in the vicinity of a nuclear plant. The question of how many people can evacuate is examined in this section.

Because an evacuation can be very stressful and socially and economically disruptive, the decision to suggest evacuating may be more difficult to make than a decision on sheltering. Hesitancy to recommend evacuation, disagreement among the local authorities, or the insistence on waiting for measurable offsite radiation may delay evacuation until it cannot be completed before contamination arrives. A multiplicity of local governments may complicate this step, but this is the most serious impact of siting on the decision phase. These problems can be addressed through agreements among local governments and predetermined guidelines on when evacuation should be advised -- aspects of effective emergency planning.

The time needed to prepare for evacuation may depend on the types of activities in the surrounding area. If families are widely separated and try to unite before leaving, the preparation time will increase. Farms or industries that require lengthy shutdown procedures could also delay the start of the evacuation for some people.[18] Explanation of the threat and the importance of moving promptly may minimize or eliminate the time devoted to shutdown. Special institutional populations (hospitals, nursing homes, schools, prisons, etc.) may require additional preparation time. Some of the delay in preparing to leave can be reduced by emergency planning and by providing supplemental evacuation instructions, such as suggestions about what to take or where the needed items might be found elsewhere. Plans to unite families after evacuation or to provide an early alert to certain industries to prepare for possible shutdown may reduce this delay. However, in most cases, the required preparation times for evacuation should not be a serious constraint to power reactor siting. When constraints to evacuation are considered, the attention is usually concentrated on the actual response phase. The capacity and location of local roadways interact with the population to determine the time required for evacuation: "Response time is a function of the volume of traffic and the capacity of the roadway."[17] On any given road segment, speed decreases when the ratio of traffic volume to road capacity increases beyond a certain point. If traffic volume exceeds roadway capacity, the speed will approach zero, resulting in stop-and-go traffic and a practical capacity that is less than the maximum possible.

However, in high population density areas, evacuation speed is even more directly tied to the condition of the existing road network; the capacity and current traffic volumes on area roads and the location of these roads in relation to major population concentrations are extremely important in determining how quickly an area could be evacuated. Areas of normally high population density may have enough increased capacity in the transportation network to accommodate the increase in the number of evacuees. Where such capacity does not exist, a phased evacuation may be necessary. Areas like parks or beaches may well have insufficient road capacity on occasion, but this can only be determined on a site-specific basis. Emergency planning might include corrective actions such as new or additional roads or bridges in such cases or emergency plans could call for early evacuation of these areas. With prompt warning and clear instructions, exposure to the release might be avoided by walking crosswind.[28]

The local road capacity may not present the only impediment to evacuation. The roads out of the evacuation area should be clear exit routes. A congested area, such as a city, just outside the evacuation area may constrict traffic flow and clog that evacuation route. The means to remove any impediments along planned evacuation routes must also be available, or suggested alternative routes may be provided. Public acceptance may be greater if the suggested evacuation routes do not require first traveling toward the nuclear plant site in order to leave the area.

Geographic constraints to evacuation also require a site-by-site analysis. Any natural feature that inhibits the rapid and direct movement of residents away from the power plant and out of the evacuation areas is considered a geographical constraint. This might include an island site with a limited number of bridges or an adjacent mountain range with only a few passes. Another example of a possible geographic constraint would be a nuclear plant located on a peninsula, leaving only one direction in which to evacuate and forcing some evacuees to move toward the plant before passing out of the evacuation zone.

Geographic constraints cannot be removed by planning, but careful planning may identify alternative protective measures. Siting decisions could eliminate sites that pose severe geographic obstacles to movement or emergency plans could include corrective actions or alternate procedures such as very early warning or restrictions on the number of people in an area where they could be trapped. Regulations limiting only population density and distribution cannot guarantee the absence of geographic barriers or the success of efforts to evacuate.

In addition, adverse meteorologic conditions may result in a delayed response by reducing road capacity. Although the 1974 evacuation study[8] found no correlation between effective evacuation speed and prevailing meteorologic conditions, the Reactor Safety Study[19] acknowledged that this result "may be partly due to the character of the available data" and that "recording errors could mask some correlations."[19] Snow, fog, and rain do, in fact, constrict traffic flow by reducing speeds or closing lanes. A recent NRC analysis of projected evacuation times at 52 nuclear plants found that in most cases adverse weather conditions were expected to result in increased response times.[27] Alternate emergency provisions during adverse meteorologic conditions may be addressed in the emergency plans, such as again requiring very early warning or insuring that snow removal equipment will be available in areas of frequent heavy snowfall.

The presence of large institutional and nonmobile populations may mean that more time is required to complete the evacuation. These facilities are a special source of concern because they are likely to demand a much higher level of outside support to achieve evacuation than will the general public. Although some of the delay will be in the preparation stage, an inadequate supply of ambulances or buses could force these vehicles to make multiple trips back to the risk area to pick up those who are too ill to travel by private car, institutional populations, or those who lack access to automobiles. There may be a time-of-day variation in the population of some institutions (i.e., schools) for which special planning may be necessary. Evacuation of some facilities such as medical centers or prisons may require special accommodations outside the emergency planning zone to receive their occupants.

In the NRC survey of projected evacuation times, response times were expected to be greater for institutional populations than for the permanent population.[27] Evacuation time may not necessarily be greater in these cases,[24] but special arrangements will be needed for those who need help in moving from the threatened area. Institutions can be safely evacuated; in the 1979 Mississauga, Ontario, evacuation, three large hospitals and six nursing homes (about 2000 patients) were evacuated without incident within 19 hours. This included 10 intensive care patients and 62 who had to be moved twice.[29]

At one extreme, the location of power plants could be restricted so as to minimize the impact of an accident on these special populations. But, because of the abundance of institutional populations, it is not unlikely that some special facility would be located near a prospective plant site. Emergency planning can help insure that many of these people could evacuate in a timely manner. Further analysis may indicate that sheltering, and not evacuation, would be a superior protective action for some nonmobile and institutional populations.[17] Only the existence of facilities that have many residents whose lives would be threatened by being moved and which are unsuitable for sheltering might be an important factor in plant siting.

Although political considerations may have the greatest impact on the decision to evacuate, expeditious response also depends on cooperation among different political entities. An evacuation area may extend to more than one jurisdiction, or the success of the evacuation could rely on the assistance of host jurisdictions in keeping the evacuation routes open. Siting regulations cannot prevent conflicts between political entities, but good emergency planning and exercises can help insure that all the responsible agencies will be able to perform adequately when the need arises.

Sensitivity to Population Density. In view of the many factors affecting the ability to evacuate an area in a timely fashion and the disagreement on the relationship between evacuation time and population density, it is impossible to reach any definite conclusions on a maximum population that could evacuate an area expeditiously in an emergency. Historical data[8] show a number of evacuations of up to a few thousand people completed in 2-5 h and a few of tens of thousands effected in similar to slightly longer times (see Appendix A). Very large evacuations are infrequent, but 150,000 people in Baton Rouge, Louisiana, were evacuated in 2 h in 1965 when threatened with a possible chlorine release after a transportation accident.[8] More recently, 600,000 people expeditiously evacuated Solinka, Greece, in the middle of the night following an earthquake.[26]

Although the Emergency Planning Zone (EPZ) may extend 10 miles, prompt evacuation would be most appropriate within 5 miles of a plant. Between 5 and 10 miles, evacuation and shelter are about equally effective in reducing prompt effects of a serious release during an accident in calculations[21] based on current source terms. Since 1974, population densities greater than 500 people per square mile have traditionally called for more intensive review of proposed reactor sites.[5] This average population density in the annulus 0.5-5 miles from the reactor would mean nearly 39,000 people subject to possible immediate evacuation. If (assuming a uniform population distribution) only one 90° sector of the 2-5 mile ring needed to be evacuated, in addition to the entire 0.5-2 mile ring, the number of potential evacuees would be reduced to just over 14,000 people, a size with which there has been more experience. Siting criteria with more restrictive population densities would reduce the number of people who might need to evacuate.

The median and mean population density projected for 2000 AD within 5 miles of existing reactor sites are about 72 and 152 people per square mile, respectively. About 92% of existing sites would be below the 500 people per square mile figure.[30] The site with the greatest projected population density within 5 miles, Limerick, would have about 99,000 people within that radius, fewer than evacuated promptly at Baton Rouge or Solinka.

Large movements of people in non-emergency situations are not unusual. Tens of thousands of people routinely "evacuate" a sports arena in a relatively short time after the end of the competition. Many thousands of commuters move in and out of the cities during the comparatively brief morning and evening rush hours. There are certainly some differences in these experiences and an emergency evacuation; commuter traffic and that following major gatherings of people is familiar, expected, and considered in planning. But nevertheless, experience with the expeditious movement of large numbers of people suggests emergency evacuation is similarly feasible; the non-emergency experience should not be dismissed lightly.

High average traffic speeds are not necessary in order for large numbers of people to move. Figure 2.1 illustrates the vehicle flow per lane as a function of vehicle speed using three spacing criteria. The middle curve represents the National Safety Council guide of one car length separation per 10 mph of speed, while the lower curve is based on

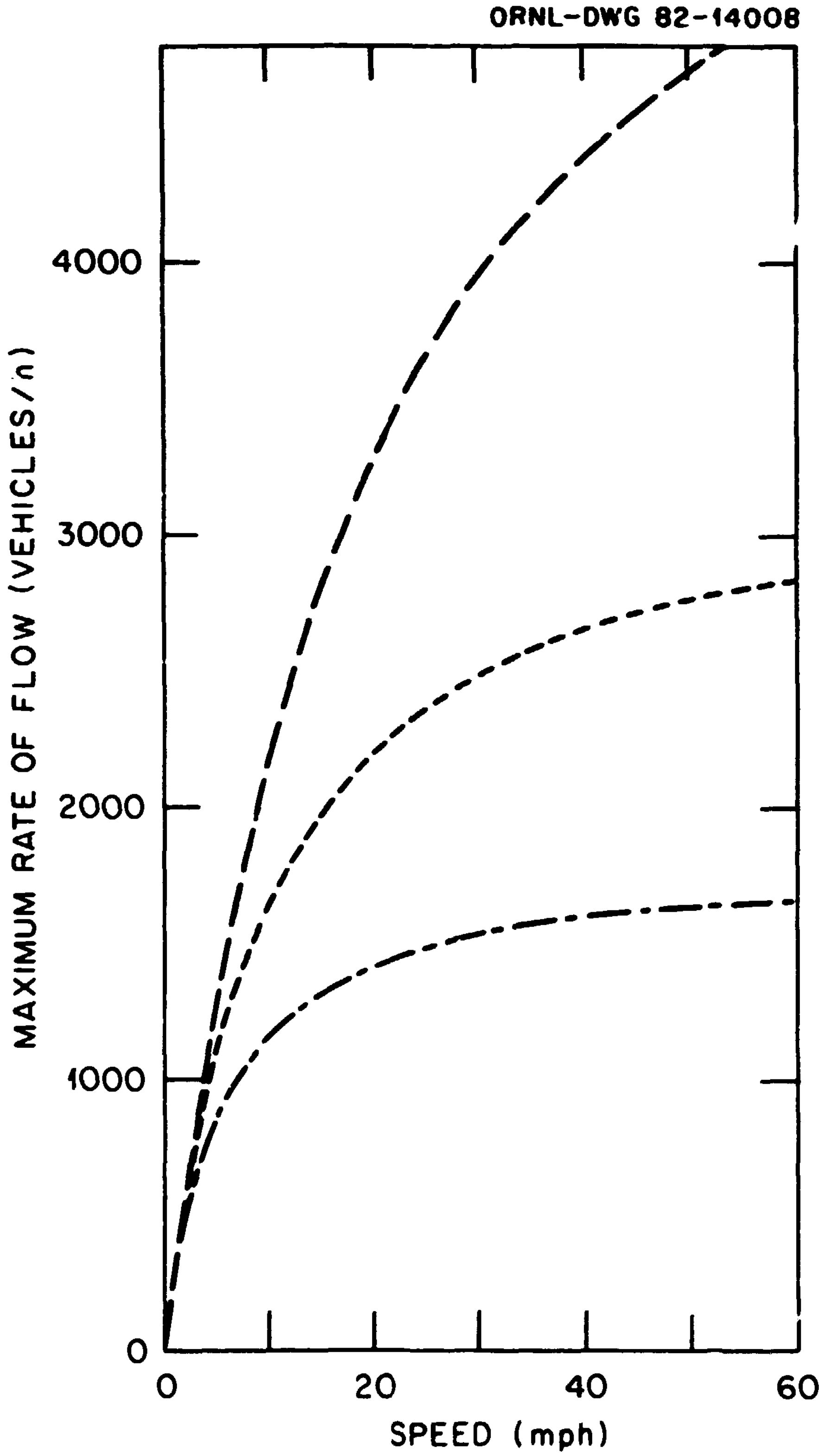

Fig. 2.1 Maximum rate of flow of vehicles per lane as a function of speed under various assumptions about minimum vehicle spacings. Lower curve - 2-s spacing between cars, middle curve - one car length for each 10 mph, upper curve - one car length for each 20 mph. Car length was assumed to be 16 ft.

the recent more conservative recommendation of a 2-s gap between cars. The upper curve assumes only one car length spacing per 20 mph, not recommended, but not an uncommon occurrence during rush hours in many areas. A recent article estimated that average rush hour speeds in some parts of Manhattan were as low as 7.4 miles per hour.[31] Assuming six lanes (not necessarily on the same road) were available and each car averaged 2.5 passengers, 15,500 people could move each hour at this speed using the conservative vehicle spacing. A modest average speed of 30 mph could increase this number to about 22,800 people per hour. Decreases in vehicle spacing or increases in average occupancy or number of lanes available would also increase the number of people who could move.

Limiting population within 5 miles of a plant would not necessarily solve the evacuation problems in that area. The people who might have to leave must be able to move freely into the surrounding area. Higher population densities in these areas can impede an evacuation of the areas near a plant. Population restrictions outside the EPZ could also be necessary. Ninety per cent of current and proposed plant sites would maintain an average projected 2000 AD population density below 500 people per square mile within 20 miles of the plant, and 85% could meet that criterion when the distance is extended to 30 miles.[30] Because 500 people per square mile is used only as a guide for site approval, or startup criterion, by 2000 AD higher populations might be expected. Projected population densities within 20 miles of all plant sites would be less than 1000 people per square mile. If the area within 30 miles of the site were considered, 95% would have projected population densities below 1000 people per square mile.[30]

Population restriction, however, cannot guarantee that a region can be evacuated, as the previous discussion of site-specific factors affecting evacuation emphasized. Experience would suggest, in general, with the lack of serious impediments, that evacuations of less than 20,000 people or so could be completed in a few hours or less. About 83% of the existing sites would have projected 2000 AD populations of less than 20,000 within 5 miles of the plant.[30]

It is more difficult to try to place an upper limit on the number of people who could evacuate in a few hours. The data on large evacuations are not as plentiful. Many of the big evacuations have been prompted by hurricanes, and there is a much larger range of evacuation times. Because of the failure to disaggregate notification, preparation, and response times in the Hans and Sell evacuation study,[8] one cannot decide if the range of times reflects the length of the period between the warning and the time the hurricane was expected to arrive. Large numbers of people have evacuated quickly in the past (for instance, 240,000 evacuated in a phased evacuation following the Mississauga train derailment[29]), but there are not enough appropriate data to make highly defensible generalizations about the feasibility of prompt evacuations involving very large numbers of people.

2.2.3 Other Protective Measures

The other protective measures previously mentioned (ventilation control, expedient respiratory protection, and pharmaceutical prophylaxis with potassium iodide) are much less dependent on siting factors for their success. Although these measures can reduce the total dose due to inhalation and mitigate the effects of inhaled or ingested radioiodines, they can only be used as supplements to sheltering or evacuation. A detailed description of these measures is found in Appendix A.

2.2.4 Notification

The discussion of notification time has been deferred until now. The time required to notify everyone of an emergency and give instructions for the recommended protective actions is independent of the type of action suggested. Site factors can affect the notification time, however. Limiting the population density around the reactor could have a negative effect on notification time if the residents are widely distributed or there are many transients. Geographic features such as hills may limit the effectiveness of portable radios or complicate the deployment of siren systems.

Adverse meteorologic conditions could also increase the notification time. A fixed siren system might be disabled by severe weather. Because many notification efforts depend on local radio and television broadcasts, electrical power outages, such as those caused by ice, heavy snowfall, or electrical storms, could cause problems. If emerjency power were maintained for transmissions, portable and car radios would still operate. Otherwise, slower, more personnel-intensive methods would have to be adopted to disseminate the necessary information.

Notification has already been addressed through the regulatory process on a site-independent basis. If the current planning goal of notification within about 15 min[32] is met, the potential notification delay expected in remote areas can be substantially reduced, increasing the probability of successful implementation of the chosen protective action.

Emergency planning has an important role in the minimization of the time between the occurrence of the accident and the instructing of the public in the appropriate protective actions. Clear channels of communication and authority and prearranged agreements on such things as action levels among all the affected jurisdictions are critical to minimizing the decision and notification times. Alternative notification procedures for use if the rapid notification system does not function can be developed as part of the emergency plan. Emergency planning can provide a means for handling any site-specific constraints on prompt notification.

3. DISCUSSION AND CONCLUSIONS

3.1 SITING BASED ON POPULATION DISTRIBUTION

The perception that the possible consequences of an accident at a nuclear power plant can be reduced by limiting the population near the plant is not new. Under the current siting criteria, exclusion areas and low population zones have been established on the basis of projected doses from hypothetical accidents at the plant. New siting criteria may prescribe a fixed exclusion area near the plant and limits on population density and distribution within a specified distance from the prospective facility site. Population density and distribution limits can reduce the number of people at risk from a reactor accident and ensure that the plant is not located near large population centers.

Efforts to reduce risk by reducing the number of people near the plant nave some limitations. Although the societal risk could be reduced by this measure, this would not reduce the individual risk to the residents of areas near the reactor. There is also always the possibility that a rare, unfavorable meteorologic condition may undo a substantial portion of the risk reduction achieved by demographic siting restrictions,[16] except in the case of extremely remote siting.

Protective actions taken by the public during an emergency can reduce the risk of injury, death, and long-term effects from a reactor accident. It is important that siting regulations not interfere with the ability of the residents to take the most effective protective measures, but, on the other hand, siting regulations cannot guarantee the success of protective actions.

3.2 CONCLUSIONS

The authors have examined protective actions and emergency planning to determine whether certain site-specific characteristics should be avoided in the selection of nuclear power plant sites because they will prevent the planning and implementation of protective measures for a severe reactor accident. It seems that restrictions on population around nuclear reactors, in general, will not adversely affect the ability to effect an appropriate emergency response. Any potential disadvantages of low population concentrations (primarily rapid notification) can be overcome by good emergency planning, although the local governments in the less urbanized areas may require more assistance in developing approved plans. On the contrary, the general assumption is that increased population density has a negative effect on protective actions. Siting planners have referred to "the relative difficulty of carrying out emergency action in thickly-populated areas."[16] Assumptions about the difficulty of implementing protective measures may depend on the particular protective action being considered:

> "Safety may, of course, be enhanced by remote siting, but too much importance has been attributed to remoteness, perhaps because among the emergency measures, the mitigation of consequences of accidents by evacuating people has received too much emphasis."[33]

Limiting the population density in the neighborhood of a nuclear plant is inherently sensible because it lowers the number of people at risk in the event of an accident. Further limits on the distribution of these people may lower the consequences expected from worst-case accidents, regardless of whether protective actions are taken. A smaller population could also conceivably result in the need for a less complex emergency plan requiring fewer resources to implement. If a fixed proportion of any given population chooses not to or is unable to take the preferred protective measures, the absolute number of individuals in jeopardy will be less for a smaller population. On the other hand, the success of protective measures for those who do participate cannot be guaranteed by reducing the number of people residing in an area. The effectiveness of evacuation and sheltering are strongly influenced by a number of factors other than population, such as road capacities, meteorologic conditions, and the availability of shelter.

The selection of prompt evacuation as the protective measure of choice in the event of a serious reactor accident may, in some instances, make the ability to evacuate an area an important factor in site selection, although this determination is usually made after the siting decision. Severe transportation and geographic constraints, as

REFERENCES

1. A. P. Hull, "Emergency Preparedness for What? (Implications of the TMI-2 Accident)," Nuclear News 24, 61, (April, 1981).

2. U. S. Nuclear Regulatory Commission, "Final Rule on Emergency Planning," Federal Register 44, 55402 (August 19, 1980).

3. 10 CFR Part 100, Reactor Site Criteria, U.S. Nuclear Regulatory Commission, Washington, 1972.

4. Report of the Siting Policy Task Force, NUREG-0625, U.S. Nuclear Regulatory Commission, Washington, August 1979.

5. General Environmental Site Suitability Criteria, Regulatory Guide 4.7, U.S. Nuclear Regulatory Commission, Washington, September 1974.

6. R. R. Dynes, E. L. Quarantelli, and G. A. Kreps, A Perspective on Disaster Planning, TR-77, Defense Civil Preparedness Agency, Washington, December 1972.

7. G. A. Kreps, "Assumptions About Individual and Social Effects of Peacetime and Wartime Nuclear Disasters," presented at the Symposium on the Control of Ionizing Radiation in the Event of Accident or Attack, National Council on Radiation Protection and Measurements, Washington, April 27-29, 1981.

8. J. M. Hans. Jr. and T. C. Sell, Evacuation Risks -- An Evaluation, EPA-520/6-74-002, National Environmental Research Center, U.S. Environmental Protection Agency, Las Vegas, NV, June 1974.

9. R. R. Dynes, The Functioning of Expanding Organizations in Community Disasters, Disaster Research Center, Ohio State University, Columbus, OH, 1968.

10. Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities, IAEA-TECDOC-225, International Atomic Energy Agency, Vienna, Austria, 1979.

11. H. G. Guyton, H. M. Decker, and G. T. Anton, "Emergency Respiratory Protection Against Radiological and Biological Aerosols," Arch. Ind. Health 20, 91 (1959).

12. J. A. Auxier and R. O. Chester, eds., Report of the Clinch Valley Study, ORNL-4835, Oak Ridge National Laboratory, Oak Ridge, TN, January 1973.

13. D. W. Cooper, W. C. Hinds, and J. M. Price, Expedient Methods of Respiratory Protection, NUREG/CR-2272 (SAND81-7143, AN), U.S. Nuclear Regulatory Commission, Washington, November 1981.

REFERENCES (continued)

14. G. L. Voltz, "Current Approaches to the Management of Internally Contaminated Persons," in The Medical Basis for Radiation Accident Preparedness, K. F. Hubner and S. A. Fry, eds., Elsevier, NY, 1980.

15. J. R. Totter, Oak Ridge Associated Universities, private communication, September 17, 1981.

16. "Siting Practice - How Much Distance?" (panel discussion), in Current Nuclear Power Safety Issues, IAEA-CN-39, Vol. I, International Atomic Energy Agency, Vienna, Austria, 1981.

17. T. Urbanik, A. Desrosiers, M. K. Lindell, and C. R. Schuller, Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones, NUREG/CR-1745 (BHARC-40180-017), U.S. Nuclear Regulatory Commission, Washington, November 1980.

18. Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA-520/1-75-001, U.S. Environmental Protection Agency, Washington, September 1975 (revised June 1980).

19. Calculation of Reactor Accident Consequences, App. VI to Reactor Safety Study, WASH-1400 (NUREG 75/014), U.S. Nuclear Regulatory Commission, Washington, October 1975.

20. D. C. Aldrich, D. M. Ericson, Jr., and J. D. Johnson, Public Protection Strategies for Potential Nuclear Reactor Accidents: Sheltering Concepts with Existing Public and Private Structures, SAND77-1725, Sandia Laboratories, Albuquerque, NM, February 1978.

21. D. C. Aldrich, P. McGrath, and N. C. Rasmussen, Examination of Off-Site Radiological Emergency Protective Measures for Nuclear Reactor Accidents Involving Core Melt, NUREG/CR-1131 (SAND78-0454), Sandia Laboratories, Albuquerque, NM, June 1978 (revised October 1978).

22. D. C. Aldrich, J. L. Sprung, D. J. Alpert, K. V. Diegert, R. M. Ostmeyer, L. T. Ritchie, D. R. Strip, J. D. Johnson, K. Hansen, and J. Robinson, Technical Guidance for Siting Criteria Development, NUREG/CR-2239, (SAND81-1549), Sandia National Laboratories, Albuquerque, NM, December 1982.

23. S. Pretr^ W. Jeschki, S. Chakraborty, A. Birrer, and M. Buggenstos, "A Possible Solution to Mitigate the Off-Site Consequences of Severe Accidents in Nuclear Power Plants," in Nuclear Power Plant Safety Issues, IAEA-CN-39, Vol. I, International Atomic Energy Agency, Vienna, Austria, 1981.

REFERENCES (continued)

24. J. A. Martin, Jr., U.S. Nuclear Regulatory Commission, "Frequency of Evacuation in U.S.," memorandum to Nuclear Regulatory Commission/Environmental Protection Agency Task Force on Emergency Planning, April 27, 1978.

25. L. T. Ritchie, J. D. Johnson, and R. M. Blond, Calculations of Reactor Accident Consequences, Version 2: User's Guide, NUREG/CR-2326 (SAND81-1994), Sandia National Laboratories, Albuquerque, NM, February 1983.

26. J. A. Martin, Jr., U.S. Nuclear Regulatory Commission, personal communication, May 1982.

27. T. Urbanik, An Analysis of Evacuation Time Estimates Around 52 Nuclear Power Plant Sites, NUREG/CR-1856 (PNL-3662). Vol. I., U.S. Nuclear Regulatory Commission, Washington, May 1981.

28. J. A. Martin, Jr., "Doses While Traveling Under Well Established Plumes," Health Physics 32, 305, (1977).

29. D. Amyot, "The Mississauga 'Saga'," Emergency Planning Digest, p. 5, (January-March, 1980).

30. Demographic Statistics Pertaining to Nuclear Power Reactor Sites, NUREG-0348, U.S. Nuclear Regulatory Commission, Washington, October 1979.

31. M. Day, "Getting There - Mastering the Midtown Madness," New York, p. 28, (May 17, 1982).

32. 10 CFR Part 50, App. E, Emergency Planning and Preparedness for Production and Utilization Facilities, U.S. Nuclear Regulatory Commission, Washington, August 1980.

33. L. P. Bachus, "Criteria for Siting Nuclear Power Plants in a Densely Populated and Industralized Country (Future Trends in the Federal Republic of Germany)," in Current Nuclear Power Plant Safety Issues, IAEA-CN-39, Vol. II, International Atomic Energy Agency, Vienna, Austria, 1981.

well as large institutional populations, may contribute to a decision on the suitability of a given site.

The most sensible approach to insuring that appropriate protective measures can be taken might be to require both that the utility identify any impediments to protective actions and that state or local emergency plans address ways in which these problems could be overcome. Identification of possible problems in evacuation is already required in the Preliminary Safety Analysis Report.[32] Extending this identification to other protective actions and addressing these problems in the emergency plans would allow imaginative, flexible, site-specific solutions to the identified situations. These solutions would be evaluated when the response plans were reviewed. Approval of the emergency plans would depend on proposed methods for removing the identified impediments or the identification of satisfactory alternatives. The ability to consider site-specific constraints, in addition to restricting population density and distribution, should help ensure that protective actions remain an effective component in reactor safety.

APPENDIX A

PROTECTIVE ACTIONS FOR USE IN RADIOLOGICAL EMERGENCIES

A.1 INTRODUCTION

Protective actions taken by the general public can decrease the health and safety consequences of radioactive releases from reactor accidents by reducing exposure to radiation. There are three principal pathways for radiation exposure after a release during a reactor accident. External radiation, both from radionuclides released from the reactor in the plume and from radioactive contamination deposited on environmental surfaces, can contribute to the whole body population exposure. Radioactive material can be inhaled from the plume or from deposited material that becomes resuspended in the air. Contamination of food and water sources can lead to ingestion of radionuclides and subsequent internal radiation exposure. Some protective actions are effective against all these exposure mechanisms, while others are specific to only one pathway.

As in the body of the report, this appendix will concentrate on measures appropriate to the time period before and shortly after radioactive material is released and focus on the inhalation and external exposure pathways. Protection of animal food to prevent contamination, for example, is a valid protective action, but the emphasis here is on prompt actions that can provide immediate dose reduction for people. Interdiction of land use (reflecting the economic consequences of the accident) is not considered.

Actions such as evacuation, which were discussed more fully in the discussion of siting considerations, will be given shorter treatment here. Emphasis will be given to the supplementary protective actions for which the effectiveness was less affected by plant location.

A.2 EVACUATION

A.2.1 Description and Use

Evacuation, the movement of the threatened population from the danger area, has been seriously considered for a number of years as a protective measure for dealing with nuclear accidents. The NRC's

Criteria for Preparation and Evaluation of Radiological Emergency Response Plans Preparedness in Support of Nuclear Power Plants[1] lists components of evacuation to be identified in emergency plans developed by power plant operators and by appropriate state and local organizations. Large evacuations, for a variety of reasons, occur frequently in the United States.[2] As a protective action in nuclear emergencies, evacuation can protect against all the mechanisms of radiation exposure because the threatened population moves out of the danger area.

Evacuation, if initiated without too much delay, can be a very effective protective measure. In calculations (using the WASH-1400[3] source terms) comparing various protective actions done at Sandia Laboratories[4], a simulated evacuation involving a 3-h delay before moving and a 10-mph travel speed was always the most effective protective measure of those considered against a melt-through release from a pressurized water reactor. It was also the most effective measure examined in reducing the projected whole-body dose due to an atmospheric release from a pressurized water reactor.

More recent calculations[5] using existing source terms also demonstrate the effectiveness of prompt evacuation. As the delay time before moving decreases and the evacuation speed increases, the number of expected early fatalities or injuries decreases. Evacuation with a 1-h delay and 10-mph speed was found to be equivalent to having a 10-mile exclusion radius around the reactor. In other words, prompt evacuation would lower the expected number of early fatalities and injuries to a number one might expect if no one lived within 10 miles of the reactor.

Urbanik et al.[6] divided the time required for evacuation into five segments: decision, notification, preparation, response, and confirmation. The first four segments must be kept brief if the residents are to leave before the arrival of the radioactive material released in the accident. A brief confirmation time may allow resources to be diverted promptly from the evacuation process, but because the residents would have left before this stage, its length is of less concern.

A.2.2 Constraints

Any factor that can increase the amount of time required to evacuate an area in the event of a radiological emergency might be considered a constraint to the use of evacuation. Five such factors are (1) population distribution, (2) transportation and geographical barriers, (3) meteorological conditions, (4) the presence of non-mobile and institutional populations, and (5) political considerations. Most constraints will lengthen the response component of the evacuation process, but they may also have negative impacts on the decision, notification, or preparation components.

There is disagreement on the relationship between population distribution and the time required to evacuate an area in an emergency. A 1974 study[7] of 64 non-nuclear evacuations found evacuation speed to be independent of the total number of evacuees and found an inverse relationship between population density and evacuation time. These data are shown in Fig. A.1 and Table A.1.

An NRC study[8] analyzed evacuation time estimates made by nuclear power plant operators for 52 separate facilities and found no correlation between total population and evacuation time. It did find a fairly strong positive correlation between evacuation time and population density for the permanent area population, although there was no significant variation in notification times. Response time was significantly less for the transient population in the high density sectors.

There are weaknesses in both these studies. The 1974 study has been criticized as not being applicable to large evacuations and to emergency planning zones having rapid notification capability. The NRC study, on the other hand, consists of time estimates based on a variety of methodologies and assumptions. Because there is little empirical data on evacuations prompted by nuclear power plant accidents to provide verfication, their conclusions must be considered tentative.

The capacity and location of roadways relative to the population can affect the amount of time required for evacuation. In order for everyone to leave promptly, the local transportation network must be

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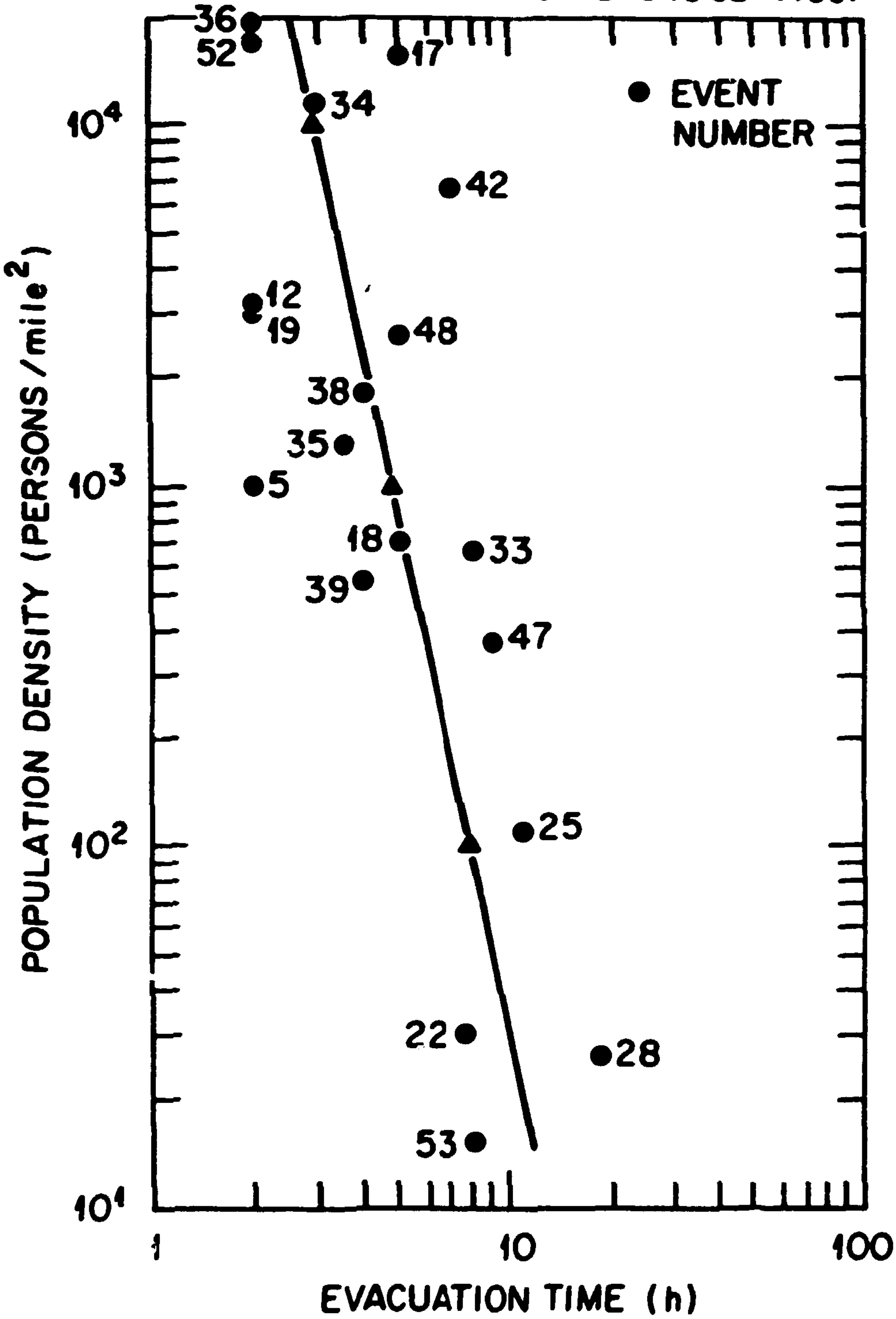

Fig. A.1 Population density as a function of evacuation time for selected historical evacuations.

Source: J. M. Hans and T. C. Sell, Evaluation Risks: An Evaluation, EPA/6-74-002, National Environmental Research Center, U.S. Environmental Protection Agency, Las Vegas, NV, June 1974.

Table A.1 Data from Historical Evacuations

Event Number	Location	Date	Cause[a]	Type of Area[b]	Number of People Evacuated	Distance Evacuated (miles)	Evacuation Time (h)	Area Evacuated (mile^2)	Population Density (people/mile^2)
5	Douglas Co., WA	9/6/72	F	S	50	1.0	2.0	2.0	1000
12	Downington, PA	2/5/73	T	S	700	1.0	2.0	0.25	3200
17	Wilkes Barre, PA	6/23/72	F	U	75000	1.0	5.0	5.0	15600
18	Chadbourne, NC	1/13/68	T	S	350	1.0	5.0	0.5	700
19	Port Aransas, TX	9/61	H	U	2800	50	2.0	1.3	3100
22	Chambers Co., TX	9/3/71	H	RF	10000	50	7.5	336	30
25	Isleton, CA	6/21/72	F	S	1200	40	11	11	109
28	King Co., WA	3/59	F	RF	500	10	18	20	26
33	Wetanka, OK	4/4/69	T	RR	2000	25	8	3	667
34	Louisville, KY	3/19/72	T	U	4000	1	3	0.35	11400
35	Urbana, OH	8/13/68	T	S	4000	0.75	3.5	3.1	1300
36	Baton Rouge, LA	8/65	T	U	150000	30	2.0	8	19000
38	Morgan City, LA	1/19/73	T	U	3000	2	4	1.8	1800
39	Texarkana, TX	8/27/67	T	S	5000	3	4	9.0	550
42	Los Angeles, CA	2/9/71	E	S	80000	ND[c]	7	12	6700
47	Lafourche Par., LA	9/11/61	H	RF	23000	50	9	100	370
48	Biloxi, MS	9/11/61	H	U	15000	5	5	7.7	2600
52	Los Angeles, CA	12/14/73	D	U	8500	ND[c]	2	0.49	17300
53	Florence Co., SC	2/13/73	F	RR	90	6	8	6	15

(a) D - Dam break
E - Earthquake
F - Flood
H - Hurricane
T - Transportation accident

(b) RF - Rural (farming)
RR - Rural (residential)
S - Suburban
U - Urban

(c) No data

Source: Adapted from J. M. Hans and T. C. Sell, Evacuation Risks: An Evaluation, EPA/6-74-002, National Environmental Research Center, U.S. Environmental Protection Agency, Las Vegas, NV, June 1974.

able to accommodate the total number of vehicles required or a phased evacuation may be necessary. Impediments along planned evacution routes must be removed, or suggested alternative routes must be available to keep traffic flowing. Population exposure to radioactivity can be minimized if the major evacuation routes are clear and if the suggested routes avoid the path of any release from the reactor. Whether or not an area has enough capacity in the transportation network to accommodate the number of evacuees can only be determined on a site-specific basis. Areas of high population density may have adequate roads, but evacuation of many areas of high transient use could be hindered by inadequate capacity.

Geographic constraints to evacuation may be imposed by the interactions of natural features of an area, plant location, and the distribution of the local population. One example of a geographic constraint would be a nuclear plant located on an island or peninsula with a significant population and a limited number of access routes, raising the possibility of severe traffic congestion at the few available points of egress. In general, any natural feature that inhibits the rapid and direct movement of residents away from the power plant is considered a geographic constraint, the effects of which must be carefully considered in planning to assure a safe and timely evacuation.

While the 1974 study[7] found no correlation between effective evacuation speed and prevailing meteorologic conditions, exception can be taken to this finding. The Reactor Safety Study[3] acknowledges that the finding of no correlation between evacuation speed and a number of potential determinants, including weather conditions, "may be partly due to the character of the available data" and that "recording errors could mask some correlations."[3] Any adverse weather condition that reduces the capacity of the roadways would probably result in a delayed evacuation response. The recent analysis of projected evacuation times at 52 nuclear plants found that adverse weather conditions were usually expected to increase response times.[8]

Evacuation can involve moving perpendicular to the radioactive plume as well as moving ahead of the contamination. Lateral movement can be very effective; the ratio of doses expected when moving crosswind as opposed to evacuating downwind under an established plume are w/(4v), w/(20v), and w/(50v) for Pascal atmospheric stability classes B (unstable), D (neutral), and F (stable), respectively. Here w is the downwind travel speed and v is the crosswind speed.[9] Typical plume widths are shown in Fig. A.2.

Although emphasis has been placed on vehicular transport because it enables many people to evacuate rapidly, vehicles are not always necessary in an evacuation. High travel speeds are not needed to avoid serious health consequences if early warning has been received. People could, in most cases, walk to safety, bypassing traffic jams and other transportation problems.[5] With early notification, all radiation exposure due to the accident could be avoided by walking crosswind.[9]

Adverse meteorologic conditions might also result in increased notification times. Since many notification efforts rely on local radio and television broadcasts as the principal means of explaining the nature of a given radiological emergency and suggesting an appropriate response to area residents, an electrical power outage, such as those caused by ice, heavy snowfalls, or electrical storms, could cause some problems. If emergency power is maintained for radio transmissions, portable and car radios would still function. Otherwise, authorities might have to resort to the adoption of alternative, and slower, methods of disseminating the necessary information.

Non-mobile and institutional populations include residents of such places as hospitals, nursing homes, jails, prisons, and schools. These facilities may need more outside assistance in evacuating than will the general public; some will also require special accommodations outside the emergency planning zone to receive their occupants. Evacuation times at 52 nuclear plants were projected to be greater for institution populations than for the permanent population.[8]

Political considerations could potentially affect the amount of time required to evacuate an emergency planning zone. The evacuation area may involve more than one political jurisdiction. Reluctance for political reasons to call for an evacuation could lengthen the amount

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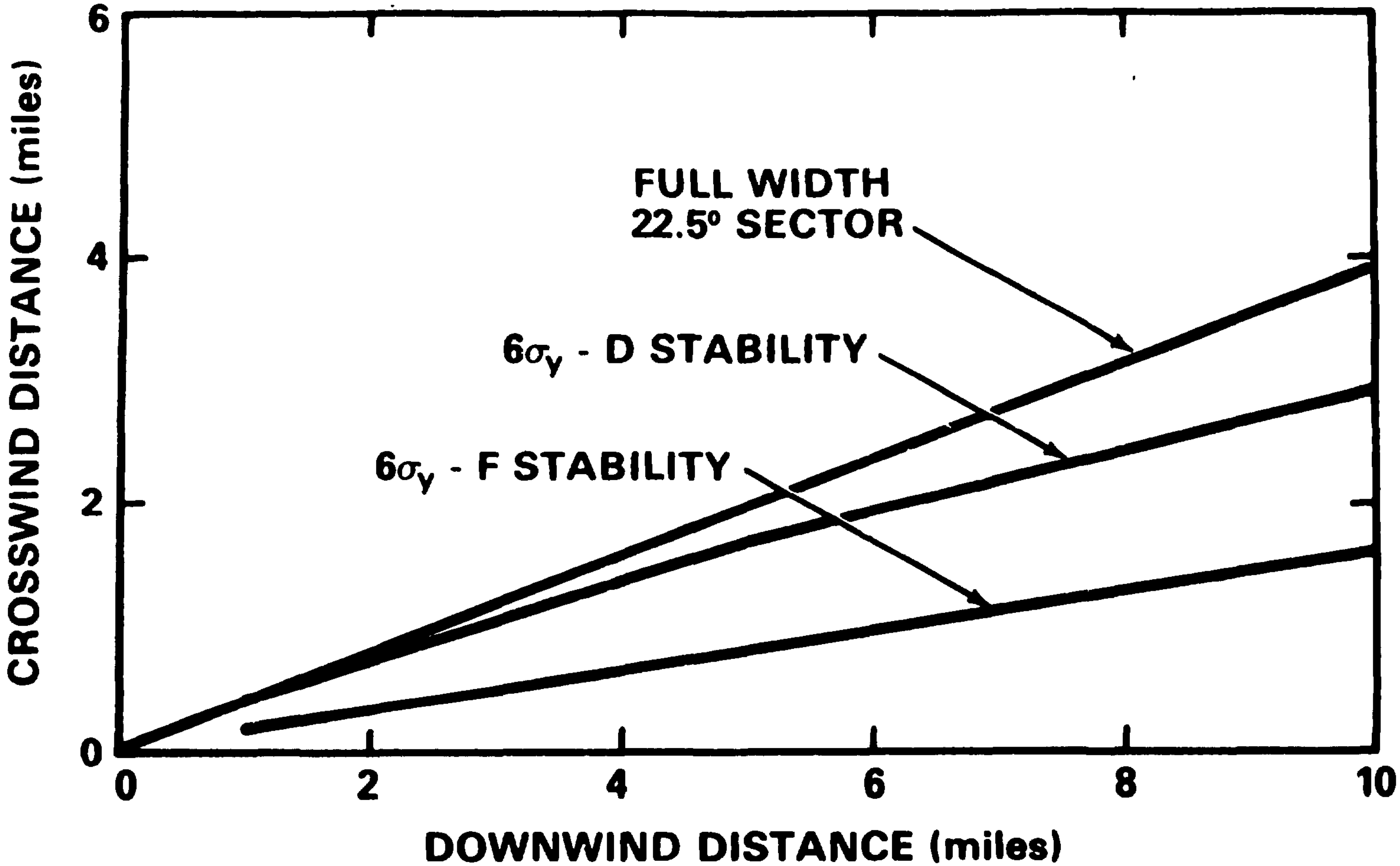

Fig. A.2 Distance across Gaussian plume as a function of distance downwind ($6\sigma y$ = full plume width at 0.01 maximum relative concentration).

Source: J. A. Martin, Jr., U.S. Nuclear Regulatory Commission, personal communication, May 1982.

of time required for the decision. Once the decision to evacuate has been made, conflicts between the different political entities may delay the evacuation process unless predetermined action levels have been agreed upon.

The effect that some of these factors may have on evacuation times is shown in Table A.2. These estimates of times for each of the first four segments of the evacuation process were published[10] by the Environmental Protection Agency. These estimates are very general; complex situations may require longer times, but a case-by-case analysis is necessary. In particular, the maximum notification and response times listed in the table would be too short for some situations, i.e., loss of power or a heavy snowstorm.

The time element in evacuation is very important. Although a delayed evacuation can be important for dose reduction, it would be better if everyone were to leave before the radioactive material arrived.

A.3 SHELTERING

A.3.1 Description and Use

Sheltering is another protective measure that can be taken to limit the radiation exposure of surrounding populations in the event of a nuclear accident. This measure has been widely considered as a supplement or alternative to evacuation for protecting individuals threatened by a radiological emergency. Sheltering might be followed by evacuation or substitute for evacuation in those cases where the numbers or nature of the population at risk, the weather, or other constraints make evacuation difficult[6] or where the available response time is extremely short.[11] Sheltering is usually the first action recommended in current emergency planning because it gets people near sources of information to await further instructions.

Sheltering consists of actions taken by the public to utilize the radiation-shielding potential of existing buildings by entering and remaining in such structures during and after the passage of a cloud of released radioactive material.[12] Two major sheltering strategies will be considered here: (1) sheltering in place, in which individuals

Table A.2 Approximate Range of Time Segments Making up the Evacuation Time[a]

Time Segment	Approximate Range Hours
Decision time	0.5 - 1.5[b]
Notification time	0.2 - 1.0[c]
Preparation time	0.2 - 2.0[d]
Response time	0.2 - 1.5[e]

[a]High population, high density areas such as those around Indian Point, present a different situation, and evacuation times are more complex, probably longer, and must be analyzed on a case by case basis.

[b]Maximum time may occur when offsite radiation measurements and dose projections are required before protective action is taken. Minimum times may occur when evacuation has been predetermined to be the appropriate response.

[c]Maximum time may occur when population density is low and evacuation area is large or when no rapid notification capability exists.

[d]Maximum time may occur when families are separated, a large number of farms or industries must be shut down, and special evacuations are required.

[e]Maximum time may occur when road system is inadequate for the large population to be evacuated and there are bottlenecks.

Source: Adapted from Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA-520/1-75-001, Environmental Protection Agency, Washington, September 1975 (revised June 1980).

remain indoors at their present location or move indoors to the nearest available structures, and (2) preferential sheltering, in which individuals move into nearby buildings offering more effective protection than those in which they are presently located. Both these strategies could be followed by evacuation or relocation, if necessary, in which individuals leave the area after passage of the radioactive cloud to limit radiation exposure from ground contamination.

Sheltering may provide protection for two radiation exposure pathways. These pathways are (1) external exposure to penetrating radiation as the radioactive cloud passes and from radionuclides deposited on the ground and other surfaces after the cloud has passed and (2) internal exposure due to the inhalation of radionuclides.[12] Protection against external radiation, or "shielding," is provided to varying degrees by different kinds of structures. Table A.3 illustrates the protection against radiation from a cloud source typically provided by various types of structures, and Table A.4 provides the same information on protection from surface-deposited radionuclides. The amount of protection afforded is given in terms of the "shielding factor," the ratio of the dose inside the structure to the dose that would be received outside the structure. These tables show that a large office or industrial building provides the most effective protection, offering several times the dose reduction of a wood-frame house. Reduction in the inhaled dose depends on the infiltration of radioactive gases or airborne contamination and can be enhanced through ventilation control or individual measures (to be discussed later).

Sheltering in areas with many basements can be as effective as evacuation with relatively short delay times in the area 5-10 miles from the reactor when existing source terms are used for the comparison.[4,13] Even in areas with few basements, sheltering and evacuation are about equally effective in preventing early fatalities and injuries in the area beyond 10 miles from the reactor.[13]

The sheltering process can also be thought of as being composed of decision, notification, preparation, and response elements. The following discussion of the major constraints to sheltering will center on the

Table A.3 Representative Shielding Factors from Gamma Cloud Source

Structure or Location	Shielding Factor[a]	Representative Range
Outside	1.0	--
Vehicles	1.0	--
Wood-frame house[b] (no basement)	0.9	--
Basement of wood house	0.6	0.1 to 0.7[c]
Masonry house (no basement)	0.6	0.4 to 0.7[c]
Basement of masonry house	0.4	0.1 to 0.5[c]
Large office or industrial building	0.2	0.1 to 0.3[c,d]

(a) The ratio of the interior dose to the exterior dose.

(b) A wood frame house with brick or stone veneer (is approximately equivalent to a masonry house for shielding purposes).

(c) This range is mainly due to different wall materials and different geometries.

(d) The reduction factor depends on where the personnel are located within the building (e.g., the basement or an inside room).

Source: Calculation of Reactor Accident Consequences, Appendix VI to Reactor Safety Study, WASH-1400 (NUREG 75/014), U.S. Nuclear Regulatory Commission, Washington, October 1975.

Table A.4 Representative Shielding Factors for Surface Deposition

Structure or Location	Representative Shielding Factor[a]	Representative Range
1 m above an infinite smooth surface	1.00	--
1 m above ordinary ground	0.70	0.47-0.85
1 m above center of 50-ft roadways, half contaminated	0.55	0.4-0.6
Cars on 50-ft road:		
Road fully contaminated	0.5	0.4-0.7
Road 50% decontaminated	0.5	0.4-0.6
Road fully decontaminated	0.25	0.2-0.5
Trains	0.40	0.3-0.5
One- and two-story wood-frame house (no basement)	0.4[b]	0.2-0.5
One- and two-story block and brick house (no basement)	0.2[b]	0.04-0.40
House basement, one or two walls fully exposed:	0.1[b]	0.03-0.15
One story, less than 2 ft of basement, walls exposed	0.05[b]	0.03-0.07
Two stories, less than 2 ft of basement, walls exposed	0.03[b]	0.02-0.05
Three- or four-story structure, 5000 to 10,000 ft^2 per floor:		
First and second floors	0.05[b]	0.01-0.08
Basement	0.01[b]	0.001-0.07
Multistory structures, >10,000 ft^2 per floor:		
Upper floors	0.01[b]	0.001-0.02
Basement	0.005[b]	0.001-0.015

(a) The ratio of the interior dose to the exterior dose
(b) Away from doors and windows

Source: Calculation of Reactor Accident Consequences, Appendix VI to Reactor Safety Study, WASH-1400, (NUREG 75/014), U.S. Nuclear Regulatory Commission, Washington, October 1975.

response element, although any major impacts on the decision-making, notification, or preparation processes will be identified.

A.3.2 Constraints

The ability to initiate sheltering in a radiological emergency is also affected by the factors discussed in regard to evacuation. Population distribution, transportation and geographic barriers, meteorologic conditions, the presence of non-mobile populations, and political considerations can influence the success of the sheltering option. In addition, there is one other major potential constraint -- the availability and accessibility of shelter.

Although any shelter provides some radiation protection, sheltering is most effective when good quality shelter is used. A shortage of easily-accessed structures with adequate shielding factors would handicap this strategy in the event of a serious nuclear accident. As shown in Tables A.3 and A.4, masonry buildings, buildings with basements, and large commercial or industrial facilities offer the best protection against external radiation. The higher the proportion of the population that resides or works in such structures, the more effective will be the "sheltering in place" approach. Preparation and response time should be minimal for those individuals utilizing on-site shelters.

"Preferential sheltering" can theoretically be used where those segments of the population that are not already in structures offering the best protection are located nearby and can move to the good shelters quickly. In addition to utilizing normally-occupied structures, the affected population could find effective shelter in existing fallout shelters or any other place with good shielding. Many planners feel, however, that if any movement is advised, evacuation should be recommended instead of moving to better shelter.

The availability of space in structures with the most effective shielding properties varies significantly from region to region. The percentage of brick housing units varies from a low of 17% on the West Coast to a high of almost 60% in the Southeast (Table A.5). There is an even greater variance in the availability of homes with basements, ranging from a low of 13% in the Southwest to a high of 87% in the

Table A.5 Percentage of Brick Housing Units by Multi-State Region

Region	Brick Housing Units (% of Total)
Northwest	47
Great Lakes	36
Southwest	40
Midwest	35
Pacific Coast	27
Atlantic Coast	45
Southeast	59

Source: D. C. Aldrich, D. M. Ericson, Jr., and J. D. Johnson, Public Protection Strategies for Potential Nuclear Reactor Accidents: Sheltering Concepts with Existing Public and Private Structures, SAND77-1725, Sandia Laboratories, Albuquerque, NM, February 1978.

Northeast (Table A.6). During working hours, the availability of sheltering for many people will be determined by the characteristics of the facilities in which they are employed. The distribution of public fallout shelters is also very uneven, with the greatest concentration being in large structures in urban areas.[14] The access of the population at risk to quality shelter is extremely important in determining whether timely use can be made of the available facilities. Rapid and early public notification of the need to seek shelter and of the location of available facilities will also be essential in order for the residents to respond.

The effect of different population densities and distributions on shelter availability is unclear. While the need for shelter is clearly greater in areas of higher population concentration, the total number of structures is also likely to increase as is the number of buildings that are well suited for sheltering, such as industrial and office complexes. Public fallout shelters are also likely to be more prevalent in urban areas. Sparsely populated areas must shelter far fewer individuals, but there is no assurance that suitable facilities would be available. In those regions where the number of brick dwellings and houses with basements are both relatively low, the effectiveness of sheltering in place during a serious radiological emergency can be limited.

Inhabitants of institutional facilities such as hospitals, nursing homes, and jails may be more likely to be sheltered in place, as opposed to being moved to an alternate location. The constraints to in-place sheltering are expected to be minor relative to those previously described for the evacuation of non-mobile and institutional populations. Furthermore, the institutional structures are likely to provide more effective radiation protection than smaller frame buildings.

Reluctance to recommend sheltering could result from fear of political repercussions. However, because fewer people would have to leave their homes during the sheltering process than during evacuation, and because any who do leave to seek better shelter nearby would generally travel shorter distances, it is easier to suggest that area residents take shelter than to recommend evacuation.

Table A.6 Percentage of Housing Units with Basements by Multi-State Region

Region	Homes with Basements (% of Total)
Northwest	87
Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia	
Great Lakes	77
Illinois, Indiana, Michigan, Minnesota, Ohio and Wisconsin	
Southwest	13
Arizona, California, Nevada, New Mexico, Oklahoma, Texas, Utah and Wyoming	
Midwest	71
Colorado, Illinois, Indiana, Iowa, Kansas, Montana, Nebraska, North Dakota, South Dakota, and Idaho	
Pacific Coast	23
California, Oregon and Washington	
Atlantic Coast	51
Connecticut, Delaware, Florida, Georgia, Maine, Maryland, Massachusetts, New Jersey, North Carolina, Rhode Island, South Carolina and Virginia	
Southeast	16
Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina and Tennessee	

Source: D. C. Aldrich, D. M. Ericson, Jr., and J. D. Johnson, Public Protection Strategies for Potential Nuclear Reactor Accidents: Sheltering Concepts with Existing Public and Private Structures, SAND77-1725, Sandia Laboratories, Albuquerque, NM, February, 1978.

A.4 OTHER PROTECTIVE ACTIONS

A.4.1 Description

Although evacuation and sheltering are the protective responses to a nuclear plant emergency that come to mind first, other actions to reduce the health consequences of an accident are possible. The measures to be discussed here are directed toward reducing the inhalation of radioactive material or preventing the radiation damage due to inhaled radionuclides. Interdiction of the inhalation pathway would be especially effective in reducing the dose to the thyroid in the event of a major release of radioiodine. These measures provide no protection against external exposure, although this weakness can be corrected by combining them with other measures, such as evacuation or sheltering, which do.

A.4.2 Expedient Respiratory Protection

Expedient respiratory protective measures can be adopted following the release of radioactivity from the reactor. The material needed for these measures is normally readily available, and implementation should be able to take place promptly. Two approaches will be discussed: (1) control of building ventilation, and (2) improvisation of air filters by the individuals at risk, for use both for filtering room air and as respiratory masks.

Remaining indoors during the passage of a radioactive cloud from a reactor accident can reduce the amount of contamination inhaled. Figure A.3 shows the concentration of radioactive material outside and indoors with time as the cloud passes. The concentration of radioactive materials indoors depends on meteorologic conditions (temperature differentials, wind speed, and wind shifts), building factors (topographic location, furnace operation, and "tightness" of construction), and particle size. Doors and windows should be closed and ventilation equip- ment turned off when a radioactive release occurs. As the ventilation rate decreases, the ratio of the inhaled dose commitment rate inside the building to that outside the building decreases,[3] increasing the advantage of seeking shelter. Simulations have shown a 35% reduction in the dose from inhaled radionuclides, even in small frame structures.[15]

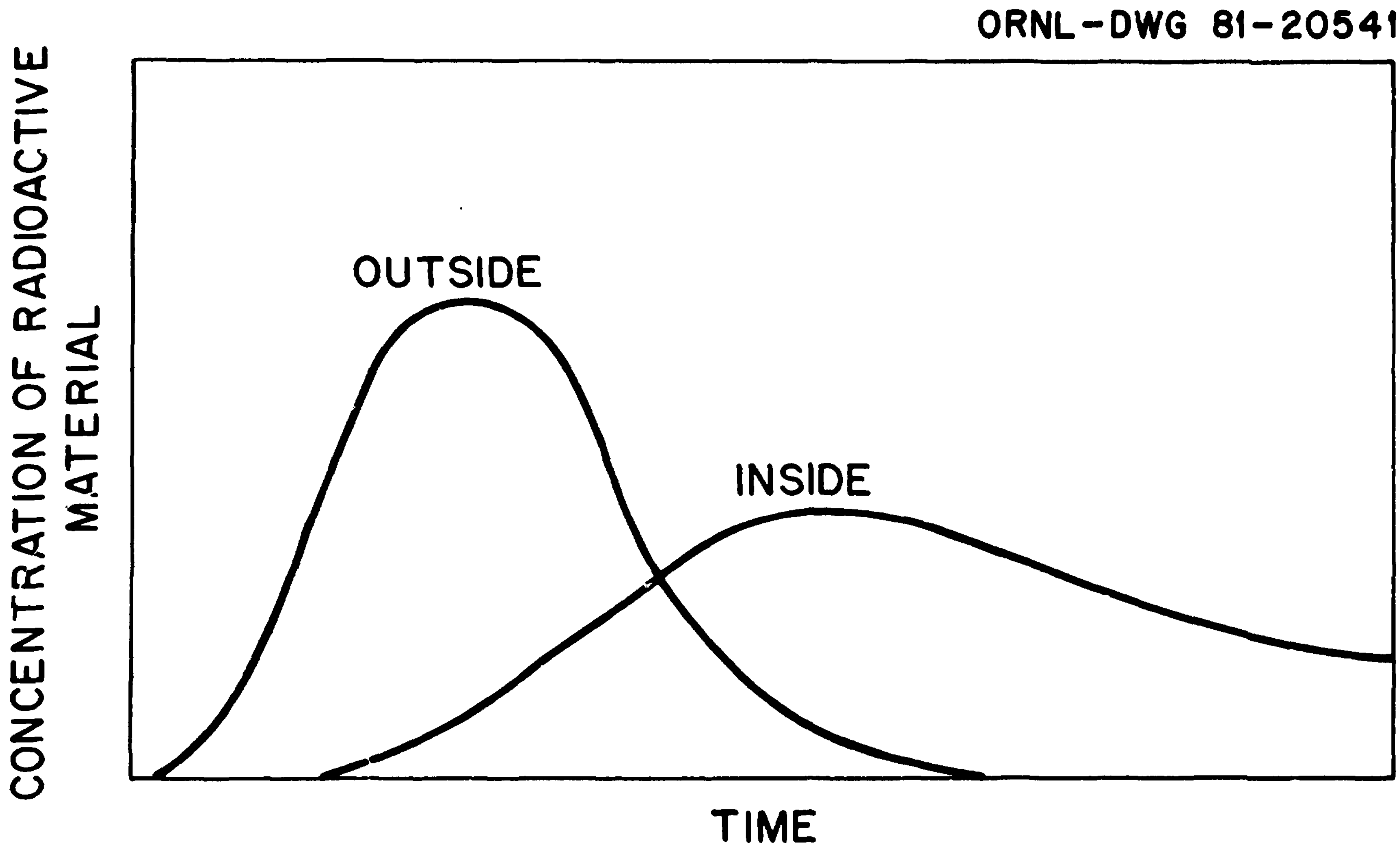

Fig. A.3 Concentration of radioactive material inside and outside a building with time following the release of radioactive materials from a reactor.

Source: Adapted from Calculation of Reactor Accident Consequences, App. VI to Reactor Safety Study, WASH-1400 (NUREG 75014), U.S. Nuclear Regulatory Commission, Washington, Oct. 1975.

In a closed structure in which the ventilation equipment has been shut down, radionuclides released during the accident can infiltrate through cracks around windows and doors, down chimneys, and through external walls and roofs. Infiltration rates vary greatly, but in most residences, interior rooms, rooms with limited exterior exposure, or closets would have the fewest air changes.[15] Staying in these areas would minimize the inhaled dose commitment rate. These rooms would be, in general, the same rooms chosen for shelter from external exposure to the cloud. Energy-efficient homes, with storm windows, caulking, or weatherstripping, would be more effective in reducing infiltration of radioactive contaminants.

Basements have been suggested for effective shelter from external radiation. Estimates by Aldrich and Ericson,[15] assuming a basement ventilation rate of half that of the upstairs, suggest significant reductions in the dose commitment rate to basement occupants from inhaled radioactive materials as compared to the inhaled dose outside.

During a radiological emergency, the effectiveness of ventilation control can be improved by further reducing the air infiltration with expedient measures such as sealing the cracks around windows and doors with moist newspapers or cloth. An additional ten-fold reduction in the inhaled dose might be obtained in this way.[16] Educational efforts could prepare people to implement these measures.

Another way to lower doses due to inhaled material would be to provide some type of filtered air supply for the house. High performance filters are commercially available, but these would not be accessible to the general public in an emergency. One expedient way to filter air involves a vacuum cleaner. Sealing off one room tightly and using the exhaust from a household vacuum cleaner to pressurize the area by drawing the air from another room lowers the inside contamination in two ways. The vacuum cleaner bag (particularly when filled with a normal collection of household dust) has been shown to be an effective filter for simulated radioactive particles. Furthermore, the slight pressurization of the sealed room helps inhibit infiltration of the outside air.[17]

The inhaled dose depends both on the concentration of radioactive material in the air and on the time it persists.[18] Radioactive materials which have "leaked" into a closed house will remain there longer if the house remains closed than if the structure is ventilated with uncontaminated outside air at an appropriate time. Figure A.3 shows that there is a time at which the concentration of radioactivity in the outdoor air falls below that inside. One solution might be for everyone to go outside at this point, but this would leave the residents unsheltered against external radiation from any contaminated material deposited on the ground. A better alternative is to open doors and windows and turn on ventilation systems to bring in the less-contaminated outside air. (Opening only windows and doors on the downwind side of the building may be advisable until the extent of any resuspended surface contamination is known.)[16] Calculations by Sandia Laboratories[15] show that the time lag between the passage of the cloud and the "opening-up" of the building is very significant in obtaining any benefits from this maneuver. For structures averaging one air change per hour, the time lag must be less than one hour and the release must be short (an hour or less) to get substantial benefit. (The more-probable high-consequence accident scenarios would involve release durations of this magnitude.)[13] If the structure can be sealed more tightly before the cloud passes, post-cloud ventilation can be very beneficial in reducing inhaled dose even with longer time lags and much longer release durations. The recent emphasis on "tightening" houses in the interest of energy conservation may make ventilation control an even more effective protective measure.

Individual respiratory protection can also reduce the amount of radioactive materials inhaled. Guyton et al.[19] showed that many common household items are effective in filtering 1-5μ particles and could provide effective respiratory protection. These results are shown in Table A.7. Although toilet paper is an effective filter material for 1-5μ particles, it would tend to disintegrate from the moisture in the breath.[20]

Table A.7 Respiratory Protection Provided by Common Household and Personal Items Against Aerosols of 1 to 5μ Particle Size

Item	Number of Thicknesses	Resistance mm of H_2O	Number of Observations	Geometric Mean Efficiency %	95% Confidence Limits for Mean, % Lower	95% Confidence Limits for Mean, % Upper
Handkerchief, man's cotton	16	36	32	94.2	92.6	95.5
Toilet paper	3	13	32	91.4	89.8	92.8
Handkerchief, man's cotton	8	18	32	88.9	85.5	91.6
Handkerchief, man's cotton	Crumbled	--	32	88.1	85.1	90.5
Bath towel, turkish	2	11	32	85.1	83.3	86.8
Bath towel, turkish	1	5	30	73.9	70.7	76.8
Bed sheet, muslin	1	22	32	72.0	68.8	74.9
Bath towel, turkish	1(wet)	3	31	70.2	68.0	72.3
Shirt, cotton	1(wet)	>150[a]	15	65.9	57.9	72.3
Shirt, cotton	2	7	30	65.5	60.8	69.6
Handkerchief, woman's cotton	4(wet)	84[a]	32	63.0	57.3	67.9
Handkerchief man's cotton	1(wet)	98[a]	30	62.6	57.0	67.5

Table A.7 (continued)

Item	Number of Thicknesses	Resistance mm of H_2O	Number of Observations	Geometric Mean Efficiency %	95% Confidence Limits for Mean, % Lower	Upper
Dress material, cotton	1(wet)	180 [a]	31	56.3	49.6	62.0
Handkerchief, woman's cotton	4	2	32	55.5	52.2	58.7
Slip, rayon	1	6	32	50.0	46.2	53.6
Dress material, cotton	1	5	31	47.6	41.4	53.2
Shirt, cotton	1	3	32	34.6	29.0	39.9
Handkerchief, man's cotton	1	2	32	27.5	22.0	32.5

(a) Resistance obtained when checked immediately after hand wringing. This resistance began to decrease after about one minute when the material started to dry.

Source: H. G. Guyton, H. M. Decker, and G. T. Anton, "Emergency Respiratory Protection Against Radiological and Biological Aerosols," AMA Arch. Ind. Health 20, 91 (August, 1959).

More measurements have now been made on the penetration of 0.4-4μ particles, as well as I_2 and CH_3I vapors, through common materials.[21] These data (Table A.8) indicate that expedient respiratory protection would be beneficial for particles of 0.5 or greater. The tests also showed that krypton gas could be delayed by the materials and that penetration of I_2 could be reduced by wetted fabrics.[21] The filter efficiency of the tested media increases with the particle size. There is evidence that in a large release from a serious accident the particles would be larger than those from small releases. Unless there is a noncondensable gas release, radioactive vapors may condense on larger dust particles in the air, making these filters more effective in this situation.[22]

When any material is held over the nose and mouth, extra effort is required to breath through the filter medium. This difficulty is measured as a pressure drop across the filter. Pressure drops of 20 mm water at 10 /min flow through 12.5 cm^2 do not require too much effort to breathe and are generally acceptable. Most commercial respiratory masks are designed for 10 mm (100 Pa) pressure. Wetting the filter may increase its filter efficiency, but this may sometimes produce such a substantial increase in the pressure drop that it would not be advisable.[23] Using a wet filter of large area, such as a bath towel, would minimize the pressure drop problem.[5]

A low pressure drop is important for effectiveness as well as comfort. The decrease in measured filter quality as the pressure drop increases is thought to be due to leakage around the material.[19] Leakage around the edge of the material may limit the dose reductions to about 25% of the unfiltered dose.[22] Ways to improve the seal around the filter medium are being investigated. The mask might be taped to the face or held on by something like nylon pantyhose.[22]

Both ventilation control and expedient filters are effective in reducing the dose due to all inhaled radionuclides. They are completely compatible with sheltering. The places in the residence which offer the best shielding against external radiation are generally areas in which the air exchange rate is less. Shelter plus expedient filtering can

Table A.8 Estimated Penetration Through Expedient Respiratory Protection Materials at 50 Pa (0.2 in H_2O) Pressure Drop and 1.5 cm/s Face Velocity

Material	No. Layers	Aerosol Particle Diameter (μm) 0.4	1	5	I_2[b]	CH_3I[b]
DRY						
3M respirator[a] # 8710	2	.03	.004	<.01		
Sheet	20	.66	.64	.020	1.0	0.6(c)
Shirt	15	.54	.59	.070		
Lower-quality towel	20	.53	.41	.015		
Higher-quality towel	6	.24	.13	<.01		0.6(c)
Handkerchief	14	.61	.54	.032		
WET						
Sheet	6	.91	.88	.22	.45 .15[d]	.8(c) 1.0(d)
Shirt	6	1.0	.51	<.02		
Higher-quality towel	4	.20	<.01	<.01	.21	1.0
Handerchief	2	.98	.95	.37	.10(d)	

(a) Available commercially in single-layer thickness.
(b) Taken from tests at 1.0 cm/s, assuming penetration is the product of single-layer penetrations.
(c) Not shown to be statistically different from 1.00.
(d) Wetted with 5% by weight baking soda solution.

Source: D. W. Cooper, W. C. Hinds, and J. M. Price, Expedient Methods of Respiratory Protection, NUREG/CR-2272 (SAND81-7143, AN), Harvard School of Public Health, Boston, MA, November 1981.

reduce the inhaled dose by factors of ten or greater.[22] Shelter plus minimal ventilation control can produce a 35% reduction in inhaled dose. Emergency sealing and post-cloud ventilation can further increase the dose savings.[15] Ad hoc filters can also be employed to reduce the inhaled dose during evacuation if the population is still relocating when the contamination arrives.

The benefits of these simple, low-risk techniques must be communicated clearly under crisis conditions and during periodic educational campaigns. Because a large reactor accident would be such an infrequent occurrence, some people may not be prepared to implement these procedures without instruction. During an actual emergency, constant communication through TV or radio would be necessary to instruct people when to close the structure and when to open the windows again. Basic safety precautions, such as extinguishing open combustion sources before sealing the house, would have to be emphasized to avoid risks of suffocation or combustion gas poisoning if sheltering were to be prolonged.

Infants[23] and other people who cannot tolerate material held tightly over their nose and mouth can rely on less effective measures (such as a blanket pulled up over the infant's head) in addition to shelter and controlling the building ventilation. Both individual filters and lack of building ventilation may become intolerable if the release is prolonged. These techniques are best suited for limited periods of exposure.

Respiratory protection is only effective in reducing the amount of radioactive material inhaled. Some protection against external radiation doses would be gained by associated actions, such as sheltering or reducing the contamination of interior surfaces through ventilation control. Expedient respiratory protection is probably best used as a supplemental action to evacuation or sheltering. By improving the protection of sheltering, the shelter-respiratory protection combination becomes a stronger alternative to evacuation and an excellent choice when evacuation is not warranted or is not feasible.

A.4.3 Pharmaceutical Prophylaxis

Pharmaceutical prophylaxis or the use of radioprotective drugs is different from the protective measures previously discussed. This action involves the use of a chemical to block the effects of the radiation exposure or to hasten the elimination of a radioactive contaminant from the body, as opposed to the other measures which were designed to prevent the exposure.

The best-known radioprotective drug is potassium iodide, used to prevent the accumulation of radioiodines in the thyroid. Protection against radioactive iodine will be discussed separately. A brief look at other drugs for possible protection against external exposure and inhalation and ingestion of other isotopes will then follow.

A large reactor accident, particularly a core-melt accident, could release large amounts of radioiodine to the atmosphere. This iodine reaches the bloodstream in the form of iodide and becomes concentrated primarily in the thyroid gland. Concentrations of iodide in the thyroid are generally 20-50 times that in the blood stream.[24] Concentration of the iodide in other tissues such as the salivary glands, parts of the gastrointestinal tract, the mammary glands, and the placenta also occurs to a lesser degree. The concentration of the radioisotopes of iodine in the thyroid causes the thyroid to receive a much larger dose of radiation than other portions of the body.

Iodine has eleven radioisotopes with atomic masses of 129 and 131 through 140. The radioisotopes with half-lives between 52.5 min and 8.05 d (^{131}I) can present problems in the early days after a reactor accident.[25] The relative contributions from these isotopes to the total absorbed thyroid dose in the first few days after a hypothetical core-melt accident would be as follows: ^{131}I, 60%; ^{133}I, 30%; ^{132}I, ^{134}I, and ^{135}I, together, 10%.[26]

Most radioactive iodine would be inhaled in the early hours after the release from the reactor containment. The other common radioiodine pathway is ingestion of contaminated milk and other foodstuffs. This pathway could be virtually eliminated after a reactor release by the immediate removal of dairy animals from contaminated pastures and confiscation of contaminated foods.

Inhalation of iodine after a severe accident could produce thyroid doses large enough to cause both acute and latent effects. The principal short-term effects are thyroiditus and hypothyroidism, although the former has such a high radiation induction threshold that it would be unlikely in the general population. Late effects include delayed hypothyroidism, benign thyroid nodules, and thyroid cancer. The human fetus can absorb radioiodine beginning about the 10th-13th week of gestation. The only well-documented effect of radioiodine on the fetus is hypothyroidism.[25]

A number of pharmacological agents that block the accumulation of radioiodine by the thyroid gland are available. They include clinical antithyroid agents, such as propylthiouracil or methimazole, and ionic blocking agents. The former category prevents synthesis of organic compounds of iodine, reducing uptake and retention as well as speeding the loss of radioiodine, but these drugs may have serious side effects. The prime mechanism for the ionic blocking agents is the saturation of the body's iodide transport system.[25] Iodide was chosen as the best choice of these compounds based on effectiveness, safety, and ease of FDA approval.[24] Potassium iodide is distributed to the public in Sweden[27] and some other countries. Great Britain, on the other hand, has concentrated on iodate (in the form of potassium iodate tablets) for radioiodine prophylaxis.[25]

When a normal person has a large single intake of radioiodine, most of the 10-40% of the radioactive material that will be retained by the thyroid is accumulated in the first 12 h. The thyroid continues to collect the radioiodine at a slower rate for the next 12 h. Stable iodide (in the form of potassium iodide) administered before or shortly after the exposure can block most of the radioiodine uptake[25] (Fig. A.4). A single dose of about 100 mg stable iodine (130 mg potassium iodide), taken within 2 h of or simultaneously with an oral dose of ^{131}I, has produced 90% or better reduction in peak radioiodine

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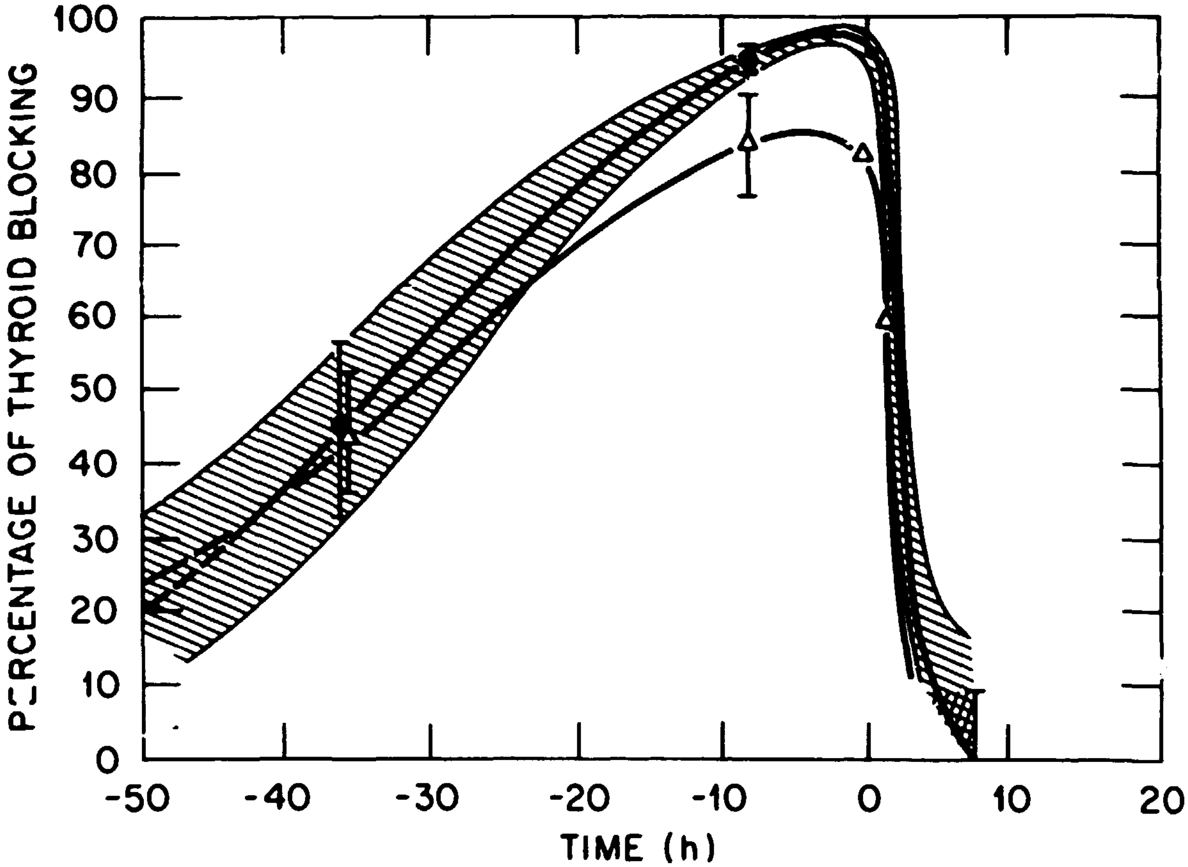

Fig. A.4 Percent of thyroid blocking afforded by 100 mg of stable iodine as a function of time of administration before or after a 1μ Ci slug intake of ^{131}I.

Source: L. A. Il'in, G. V. Arkhangel'skaya, Yu. O. Konstantinov, and I. A. Likhtarev, Radioactive Iodine in the Problem of Radiation Safety (USSR, 1972), AEC-tr-7536, U. S. Atomic Energy Commission, Technical Information Center, Oak Ridge, TN, 1974.

accumulation in the thyroid.[28] A reduction of 50% or more is attainable only if the potassium iodide is taken within the first few hours after single exposure.[25,29]

Daily doses of 130 mg potassium iodide could be continued for at least 3 days until most of the radioiodine still in the bloodstream is excreted,[25] but one large early dose would be as effective for a slug intake.[28] Longer treatment would be necessary if there is continuing exposure to radioactive iodine. These doses can be continued without probable toxic effects for 7-10 days.[25] Although toxicity would not be expected in the young when taking the adult dose,[25] the FDA recommends halving the dosage (65 mg potassium iodide) for infants under the age of one.[26]

Potassium iodide has been available in the United States in solution. Single doses of this solution are stored in dark glass ampules.[25] The FDA has approved New Drug Applications for scored 130 mg tablets and a bottle of solution with a calibrated medicine dropper.[24]

If large releases of radioiodine from a nuclear power plant have occurred or are imminent, timely administration of potassium iodide can be very effective in lowering the dose to the thyroid and reducing the consequences of the accident. If taken before or within 2 h after exposure, it is more than 90% effective in blocking radioiodine uptake by the thyroid gland, but clear guidance on when potassium iodide should be used has not been issued. NCRP-55 suggests considering its use if the absorbed thyroid dose to the general public is expected to exceed 10 rad.[25] The Environmental Protection Agency has suggested some type of protective action at a projected thyroid dose to the general public of 5-25 rem but does not include potassium iodide prophylaxis on its list.[10] Questions as to the projected thyroid dose and the timing of the blocking drug led to the decision not to use the drug when supplies of potassium iodide were obtained after the accident at Three Mile Island.[30]

Although the question of side effects is frequently raised, the incidence of serious side effects from short-term administration of daily 130 mg doses of potassium iodide would be expected to be very low. Much larger daily doses on a long-term basis have been used for years in the management of pulmonary disorders.[24]

NCRP-55[25] lists the known side effects of iodide administration. These include hyperthyroidism, hypothyroidism, and iodide goiter, as well as skin eruptions, swollen parotid glands, and iodism. These complications are rare and, when seen, have occurred at much larger doses of iodide. People with pre-existing thyroid damage may be more susceptible to the thyroid side effects.[25] Even so, a known allergy to iodide would probably be the only reason not to use potassium iodide in a radiation emergency.[24] As a precaution, however, the public and area physicians should be made aware of possible side effects of potassium iodide and what to do if they occur.

The administrative problems associated with the use of potassium iodide may be a greater constraint. In order to have the emergency use of potassium iodide as an option, the drug must be stockpiled securely near the reactor site. These stockpiles would have to be replaced periodically. (The expiration date is now two years, but stability studies are underway.)[24] Detailed plans for emergency distribution of the drug to the people at risk must be formulated. There are political and public health questions affecting the decision to give any drug, regardless of its safety, to large segments of the population.[30] Getting correct and appropriate information to a concerned public could be a public information problem if it is not worked out in advance. If potassium iodide is made available to the general public in a radiation emergency, monitoring programs should be set up to test its effectiveness as a thyroid block and to check out promptly any reports of side effects.

Thyroid blocking cannot be separated from other protective measures and must be considered only a supplemental strategy. Evacuation, sheltering, and expedient respiratory protection can provide at least the same degree of thyroid protection as potassium iodide alone, in addition to protection against exposure to radioactive materials other than radioiodine. Because of this limitation, one study has questioned the cost effectiveness of implementing a potassium iodide program for the general public.[29]

Potassium iodide may prove more cost effective as a protective measure for site personnel and emergency workers.[29] These groups will be at greater risk due to the higher thyroid exposures expected on and near the reactor site. Although respirators may also be feasible for these groups, thyroid blocking may be initiated more easily for them than for the general population. Stockpiling and emergency distribution of the drug can be handled through their usual administrative chains. The smaller population can be monitored for side effects along with the routine radiological monitoring during the emergency.

Even with these difficulties, the option for thyroid blocking may be an important part of a feasible emergency response. Non-mobile and institutional populations that could not evacuate easily might benefit greatly from its use. Because this measure can provide some benefit after the exposure, it could be an important supplementary measure for the general public when evacuation takes place after the exposure to radioiodine.

A number of other radioprotective drugs have been used to reduce the health effects due to internal exposure to radionuclides, but these procedures are generally implemented only when the exposure greatly exceeds the permitted guidelines for radiation workers. Two general processes employed are these: (1) reduction of absorption and internal deposition, and (2) enhanced elimination. Stable strontium, phosphate, and calcium, for example, can respectively, dilute, decrease intestinal absorption, and speed excretion of radiostrontium. For a brief summary of the use of these compounds, as therapy for selected elements, see Ref. 31.

Most medical procedures are more easily directed toward ingested contamination. Effective management of contaminated food and water resources after a reactor accident should eliminate this pathway. Inhaled contamination presents greater problems because the response depends on the person's history and the form of the contamination;[32] insoluble forms reach the bloodstream so slowly that administration of a drug is not effective. Expectorants and inhalants have not proven useful in treating people who have inhaled radioactive particles.[31] Studies on the use of prophylactic agents for radiocesium and radiostrontium from reactor accidents were recommended by the Clinch Valley Study in 1972.[23] No drugs suitable for distribution to the general public for these two radioactive elements are yet available.

Some pharmaceutical development is occurring in drugs that provide limited protection against external radiation. These drugs appear to work by interfering with the chemical mechanisms responsible for radiation damage. A class of sulfahydrol compounds, such as mercaptoethylamine, can raise the radiation tolerance two to three times, but these drugs must be given in near toxic levels before irradiation. An enzyme, superoxide dismutase, shows promise in this regard. It appears to be less toxic at effective levels and retains some effectiveness when given after the exposure.[33]

While development of radioprotective drugs other than potassium iodide could benefit the victims of industrial radiation accidents and patients undergoing radiotherapy, they have no role at this time as a protective action for the general public. The risks of pharmaceutical treatment would override the risk of the radiation exposure expected for the general public.

Because of its availability and low toxicity, potassium iodide is the only radioprotective drug approved for general distribution. It can be effective in reducing the thyroid dose from exposure to radioiodines that might be incurred by the public after a release during a nuclear reactor accident. Decisions concerning its use will be made not only on a risk from drug vs risk from radiation basis, but also on its usefulness and cost-effectiveness in comparison with other protective actions.

APPENDIX A

Protective Actions For Use In Radiological Emergencies

REFERENCES

1. Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, NUREG 0654, (FEMA-REP-1), Rev. 1, U.S. Nuclear Regulatory Commission and Federal Emergency Management Agency, Washington, November 1980.

2. J. A. Martin, Jr., U.S. Nuclear Regulatory Commission, "Frequency of Evacuation in U.S.," memorandum to Nuclear Regulatory Commission/ Environmental Protection Agency Task Force on Emergency Planning, April 27, 1978.

3. Calculation of Reactor Accident Consequences, App. VI to Reactor Safety Study, WASH-1400 (NUREG 75/014), U.S. Nuclear Regulatory Commission, Washington, October 1975.

4. D. C. Aldrich, P. McGrath, and N. C. Rasmussen, Examination of Off-Site Radiological Emergency Protective Measures for Nuclear Reactor Accidents Involving Core Melt, NUREG/CR-1131 (SAND78-0454), Sandia Laboratories, Albuquerque, NM, June 1978 (revised October 1978).

5. J. A. Martin, Jr., U.S. Nuclear Regulatory Commission, personal communication, May 1982.

6. T. Urbanik, A. Desrosiers, M. K. Lindell, and C. R. Schuller, Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones, NUREG/CR-1745 (BHARC-401/80-017), U.S. Nuclear Regulatory Commission, Washington, November 1980.

7. J. M. Hans and T. C. Sell, Evacuation Risks: An Evaluation, EPA/ 6-74-002, National Environmental Research Center, U.S. Environmental Protection Agency, Las Vegas, NV, June 1974.

8. T. Urbanik, An Analysis of Evacuation Time Estimates Around 52 Nuclear Power Plant Sites, NUREG/CR-1856 (PNL-3662, Vol. I), U.S. Nuclear Regulatory Commission, Washington, May 1981.

9. J. A. Martin, Jr., "Doses While Traveling Under Well Established Plumes," Health Physics 32, 305, (1977).

10. Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA-520/1-75-001, Environmental Protection Agency Washington, September 1975 (revised June 1980).

11. M. Levenson and F. Rahn, Realistic Estimates of the Consequences of Nuclear Accidents, Electric Power Research Institute, Palo Alto, CA, November 1980.

REFERENCES (continued)

12. D. C. Aldrich, D. M. Ericson, Jr., and J. D. Johnson, Public Protection Strategies for Potential Nuclear Reactor Accidents: Sheltering Concepts with Existing Public and Private Structures, SAND77-1725, Sandia Laboratories, Albuquerque, NM, February 1978.

13. D. C. Aldrich, J. L. Sprung, D. J. Alpert, K. V. Diegert, R. M. Ostmeyer, L. T. Ritchie, D. R. Strip, J. D. Johnson, K. Hansen, and J. Robinson, Technical Guidance for Siting Criteria Development, NUREG/CR-2239 (SAND81-1549), Sandia Laboratories, Albuquerque, NM, December 1982.

14. C. M. Haaland and K. S. Gant, Instrumentation Requirements for Radiological Defense of the U.S. Population in Community Shelters, ORNL-5371, Oak Ridge National Laboratory, Oak Ridge, TN, August 1979.

15. D. C. Aldrich and D. M. Ericson, Jr., Public Protection Strategies in the Event of a Nuclear Reactor Accident: Multicompartment Ventilation Model for Shelters, SAND77-1555, Sandia Laboratories, Albuquerque, NM, January 1978.

16. Planning for Off-Site Response to Radiation Accidents in Nuclear Facilities, IAEA-TECDOC-2250 (working document), International Atomic Energy Agency, Vienna, Austria, December 1979.

17. G. A. Cristy and C. V. Chester, Emergency Protection from Aerosols, ORNL-5519, Oak Ridge National Laboratory, Oak Ridge, TN, July 1981.

18. W. J. Megaw, "The Penetration of Iodine into Buildings," Int. J. Air Wat. Poll. 6, 121 (1962).

19. H. G. Guyton, H. M. Decker, and G. T. Anton, "Emergency Respiratory Protection Against Radiological and Biological Aerosols," AMA Arch. Ind. Health 20, 91 (August, 1959).

20. Respiratory Protective Devices Manual, American Industrial Hygiene Association, American Conference of Industrial Hygienists, 1963.

21. D. W. Cooper, W. C. Hinds, and J. M. Price, Expedient Methods of Respiratory Protection, NUREG/CR-2272 (SAND81-7143, AN), Harvard School of Public Health, Boston, MA, November 1981.

22. J. A. Martin, Jr., Nuclear Regulatory Commission, "On the Efficiency of Ad Hoc Respiratory Protection During a Radiological Emergency," presented at the 26th Annual Meeting of the Health Physics Society, Louisville, KY, June 21-25, 1981.

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55. T. R. LaPorte, Institute of Government Studies, University of California, 109 Moses Hall, Berkeley, CA 94720.

56. T. McKenna, Incident Response Branch, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

57. J. A. Martin, Jr. (NL), Division of Risk Analysis, U.S. Nuclear Regulatory Commission, Washington, DC 20555

58. L. I. Moss, Energy/Environmental Design and Policy Analysis, 5769 Longs Peak Route, Estes Park, CO 80517

59. Office of Assistant Manager for Energy Research & Development (DOE/ORO), Federal Building, Oak Ridge, TN 37831

60-70. W. R. Ott, Waste Management Branch, MS1130-FS, U.S. Nuclear Regulatory Commission, Washington, DC 20555

71. M. Russell, Center for Energy Policy Research, Resources for the Future, 1755 Massachusetts Avenue, NW, Washington, DC 20036

72. W. H. Williams, AT&T Information Systems, Building 83, Room 1P23, 100 Southgate Parkway, Morristown, NJ 07960.

73-99. Technical Information Center, Department of Energy, POB 62, Oak Ridge, TN 37831.

REFERENCES (continued)

23. J. A. Auxier and R. O. Chester, ed., Report of the Clinch Valley Study, ORNL-4835, Oak Ridge National Laboratory, Oak Ridge, TN, January 1973.

24. J. A. Halperin, B. Shleien, S. E. Kahana, and J. M. Bilstad, Background Material for the Development of the Food and Drug Administration's Recommendations on Thyroid-Blocking with Potassium Iodide, FDA 81-8158, U.S. Department of Health and Human Services, Rockville, MD, March 1981.

25. Protection of the Thyroid Gland in the Event of Releases of Radioiodine, NCRP Report No. 55, National Council on Radiation Protection and Measurements, Washington, August 1977.

26. Potassium Iodide as a Thyroid-Blocking Agent in a Radiation Emergency: Proposed Recommendations on Use (draft recommendations), Bureau of Radiological Health and Bureau of Drugs, U.S. Department of Health and Human Services, Rockville, MD, April 1981.

27. T. Eckered, "KI Distribution in Sweden," in Are Current Emergency Planning Requirements Justified?, Proceedings of a workshop, January 1982, Bethesda, MD, J. J. Cohen, C. F. Smith, and R. J. Caitlin, ed., NSAC-50, Nuclear Safety Analysis Center, Electric Power Research Institute, Palo Alto, CA, May 1982.

28. L. A. Il'in, G. V. Arkhangel'skaya, Yu. O. Konstantinov, and I. A. Likhtarev, Radioactive Iodine in the Problem of Radiation Safety (USSR, 1972), AEC-tr-7536, U.S. Atomic Energy Commission, Technical Information Center, Oak Ridge, TN, 1974.

29. D. C. Aldrich and R. M. Blond, "Radiation Protection: An Analysis of Thyroid Blocking," in Current Nuclear Power Plant Safety Issues, IAEA-CN-39, Vol. II, International Atomic Energy Agency, Vienna, Austria, 1981.

30. G. K. MacLead, The Decision to Withhold Distribution of Potassium During the Three Mile Island Event: Internal Working Document, Commonwealth of Pennsylvania, Harrisburg, PA, April 1979.

31. G. L. Voitz, "Current Approaches to the Management of Internally Contaminated Persons," in The Medical Basis for Radiation Accident Preparedness, K. F. Hubner and S. A. Fry, ed., Elsevier, NY, 1980.

32. G. A. Poda, "Decontamination and Decorporation: The Clinical Experience," in The Medical Basis for Radiation Accident Preparedness, K. F. Hubner and S. A. Fry, ed., Elsevier, NY, 1980.

33. J. R. Totter, Oak Ridge Associated Universities, private communication, September 17, 1981.