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Graded Response: The Preferred Evacuation Strategy for Nuclear Power Plants

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GRADED RESPONSE: THE PREFERRED EVACUATION STRATEGY FOR NUCLEAR POWER PLANTS

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EXECUTIVE SUMMARY

This report is primarily directed at local, state, and federal officials involved in emergency planning, as well as utility executives, legislative groups, and the public. It attempts to overcome some common misperceptions about emergency responses to severe nuclear power plant accidents classified as General Emergencies. This report draws upon actual practice and analyses from the regulatory, emergency planning, and risk assessment communities. A technical appendix is provided, as well as numerous references, to assist those who would like to review this subject in greater detail.

Discussions and implementation of full-scale simulated training exercises related to hypothetical General Emergencies at nuclear plants often assume the immediate evacuation of everyone within the 10-mile Emergency Planning Zone, or EPZ. Thus the "E" in EPZ has incorrectly come to mean, for many, "evacuation" instead of "emergency." This misperception is in contrast to federal guidance which, in a General Emergency, calls for very localized responses in the immediate vicinity of the plant. Often, the first recommendation during a General Emergency is sheltering.*

The goal of this report is not to merely correct misperceptions about nuclear emergency responses. Of much greater importance is the description of an evacuation response that is far more protective of the public than immediate evacuation of the entire EPZ. It is, therefore, the preferred

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*See "Criteria For Protective Action Recommendations For General Emergencies," USNRC, IN83-28, May 4, 1983.

evacuation response. This protection is called the Graded Response. Once it has been decided to evacuate, the Graded Response uses a combination of rapid evacuation near the plant and sheltering elsewhere, as appropriate, within the 10-mile emergency planning zone. Although prompt evacuation of areas near the plant is a key aspect of the Graded Response, only about one percent of the EPZ population would be advised to take this action. Some portion of the sheltered population might be relocated after the prompt evacuation phase is completed. Relocation of sheltered persons would only be advised if actual offsite radiation measurements of ground contamination, or projections of such measurements, determine that this was warranted.

The Graded Response is based on very conservative assumptions. Nonetheless, analyses show that if the Graded Response were fully utilized following a significant release of radioactive material into the environment, virtually no early fatalities would be expected, even at the most populated sites. Fewer other health effects, such as latent fatalities, would be expected if the Graded Response were used instead of an area-wide evacuation. The Graded Response has great flexibility, it allows emergency responses to be matched to the hazards at hand. This would direct much more efficient use of resources to those persons at potential risk.

In order for there to be a declaration of a General Emergency, events which involve actual or imminent substantial degradation or melting of the reactor core must be in progress or have occurred. Assuming that a General Emergency has already been declared and further assuming that an evacuation response to this general emergency has been selected due to an anticipated or actual release of radioactive material into the environment, the Graded Response would utilize a sequence of

steps such as:

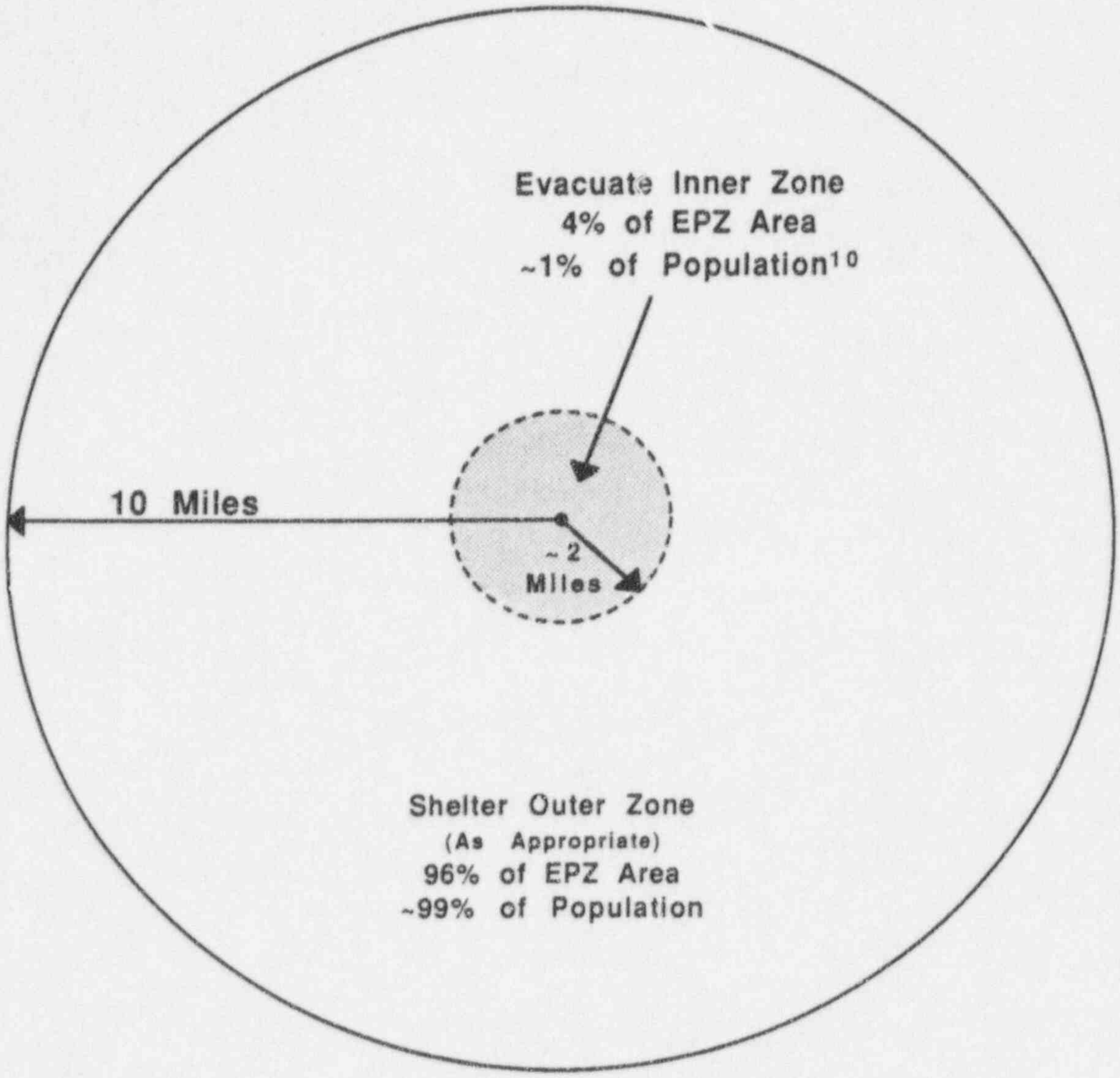
1. Notify the public to evacuate an inner zone around the plant of about 2 miles in radius while advising others within the EPZ to take shelter and wait for additional instructions via the radio, television or other means of communication.

2. Evaluate the findings of radiation monitoring teams and/or other data to determine the direction and speed that the radioactive plume (if any) is traveling and the deposition of radioactive material on the ground and other surfaces.

3. Notify sheltered people in the EPZ to relocate out of areas downwind of the plant, if the above offsite monitoring surveys and/or other data reveal that they are or are expected to be in areas of ground contamination with unacceptably high dose rates.

Implementation of the Graded Response does not require changes to the Nuclear Regulatory Commission or FEMA regulations and does not assume a reduction in the size of the EPZ. It would, however, require a change in the current full-scale exercise and planning philosophy, such as demonstrating that resources are available to simultaneously evacuate the entire EPZ.

THE GRADED RESPONSE STRATEGY



Phase #1: Notify public to evacuate an inner zone of about a 2 mile radius and to shelter those in the outer zone (as appropriate).

Phase #2: Monitor radiation levels.

Phase #3: Notify sheltered people in plume pathway to relocate if measured offsite radiation levels of ground contamination are too high or are expected to become too high based on extrapolations of these measurements and/or other data.

EXECUTIVE SUMMARY i

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1.0 PLANNING FOR EMERGENCIES: NUCLEAR AND NON-NUCLEAR

1.1 Similarities

There are a number of characteristics that are common to a wide range of emergencies, be they of a nuclear or non-nuclear (industrial or natural) origin. For many non-nuclear emergencies -- fires, releases of toxic or explosive gases, etc. -- the risks depend heavily on the distance an individual is located relative to the source of the release and the amounts of the hazardous material released to the environment. Released hazardous material becomes more dilute as the distance from the point of release increases. Such decreases in the concentration of hazardous material is a natural process called diffusion and does not require any human intervention to bring it about. As the concentration of hazardous material decreases, the kinds of health effects that may result from such releases also change. The area in which an accident might be capable of causing an early fatality* usually is quite localized. Beyond this limited area there is little likelihood of a fatality, but there remains the possibility of injury (from smoke inhalation, for example). Once out of the immediate injury range, the remaining health concerns are long term effects.

People supplement the dilution protection afforded by nature by two general processes, barriers (sheltering) and evacuation. Barriers, such as buildings, protective clothing, air filters, etc. serve to reduce the exposure of an individual at a given location. Evacuation results in moving the

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*A fatality that occurs relatively soon after exposure, e.g., within 60 days.

individual to an area of lower concentration, thereby diminishing or eliminating certain health risks. Combinations of both human protective actions, use of barriers and evacuation, are often utilized during emergencies.

Nuclear power accidents are no exception to this. If a significant amount of radioactive material were released from a nuclear power plant, it would be in the form of a radioactive plume. The plume would travel like smoke from a smokestack. As it travels with the wind it rapidly becomes diluted. By the time a radioactive plume travels 2 miles, its dose rate would typically be reduced by as much as 90 percent (see Appendix B, Figure 2). Immediate health risks from nuclear accidents would similarly decrease rapidly with the distance from the plant. This means that the population most at risk would be those closest to the plant -- within about 2 miles -- and those within that area downwind of the plant. Accordingly, initial emphasis should be placed on strategies that quickly and efficiently protect people living in these nearby areas. The protective actions that would be used in a nuclear accident, taking shelter or evacuation, would parallel the protective actions used for responding to non-nuclear accidents.

Because of the above similarities, nuclear emergency plans have been used to respond to many non-nuclear emergencies. Nuclear emergencies are but one member of a larger group of similar emergencies.

1.2 Differences

Frequency and timing are two major differences between nuclear and many non-nuclear emergencies.

Because of the way nuclear power plants are designed and operated, the frequency at which a General Emergency might be

declared is very low. Estimates of core melt accidents range from about once in ten thousand to about once in a hundred thousand years, per plant. Releases of radioactive material to the environment would only occur for a fraction of these core melt accidents. In the history of nuclear power operation in the United States, the only General Emergency that has been declared was during the 1979 accident at Three Mile Island. In that case the subsequent evacuation turned out to be precautionary since the amount of radioactive material released was extremely small.

Although both experience and analyses have shown that nuclear emergencies requiring an offsite response is indeed unlikely, nuclear emergency preparedness takes no credit for this.

There are also differences between nuclear and non-nuclear accidents beside the fact that non-nuclear accidents occur more frequently. Many non-nuclear emergencies are sudden, with little or no time for precautionary steps: dam breaks, earthquakes, tornadoes, explosions, airplane crashes, sudden releases of gas or toxic materials. These emergencies require immediate action because the hazard is already present by the time it becomes recognized. By contrast, experience and research have demonstrated that the nuclear emergency response organization would generally have much more time to react.

Recent studies for the Department of Energy by Sandia National Laboratories have shown that for even the most serious nuclear power plant accidents, the amount of time between accident initiation and any release of radioactive material to the environment is almost always longer than 2 hours, and often a day or longer. One reason for this is that nuclear plants have multiple barriers, the outer barrier being a strong containment structure that completely encloses the nuclear

reactor. Recent analyses and large scale experiments have shown that nuclear power plant containments can actually withstand internal pressures at least 2 1/2 to 3 times greater than their design pressures.[1,2]

Thus, nuclear accidents are both far less likely to occur than non-nuclear accidents and would typically evolve slowly, giving ample time for offsite responses.

2.0 NUCLEAR POWER PLANT EMERGENCIES

2.1 Background

The goal of emergency preparedness at nuclear power plants in the United States is to protect public health and safety in the event of a major accidental release of radioactive material to the environment. Federal emergency preparedness requirements, together with the detailed plans and procedures of state and local agencies and the utilities that operate nuclear power plants, constitute the most comprehensive emergency preparedness program for any industrial activity.

Emergency plans developed and tested for U.S. nuclear power plants are being applied to a mature industry that has a firmly established record of performance and safety. Nuclear power plants have been operating in the United States for more than three decades, since the start-up of the Shippingport station in Pennsylvania in 1957.

In the United States, more than 100 nuclear plants are now licensed to operate. Collectively they have accumulated more than 1,150 operating-years of experience. In this time, there has never been an accident at a U.S. nuclear power plant that has resulted in a radiation related injury to any member of the public[3].

From the outset of the industry, nuclear power plants have been designed, constructed and operated with an overriding consideration for public health and safety. Nuclear plants have large margins for safety, including redundant safety systems. Plants are also designed with a series of physical barriers to prevent radioactive material from escaping into the environment -- including the massive concrete-and-steel containment building. Thus, in order for there to be a release

of radioactive material to the environment, a highly unlikely series of multiple failures would have to occur. Analyses have shown that the probability of a nuclear plant accident causing a severe release of radioactive material is less than about once in a hundred thousand years per plant.

To prepare even for this remote possibility, regulations have included detailed emergency planning requirements for the communities surrounding nuclear plants[4]. In 1975, the NRC recommended emergency planning for the population within about a 3-mile radius around plants[5]. In 1978, the NRC established a 10-mile radius EPZ for the planning of evacuation and/or sheltering to protect the public from exposure to releases of radioactive material from nuclear power plant accidents[6].

Utilizing criteria established in 1980 by the NRC and FEMA[7] every nuclear power plant must have a comprehensive emergency response plan, addressing both onsite and offsite areas. These plans are regularly tested with exercises and drills that simulate emergencies and include the participation of the responsible agencies.

Emergency plans must include details about the specific sequence of steps that would be initiated by emergency conditions at a nuclear power plant, depending on the severity.

The declaration of an emergency at a nuclear power plant triggers the notification of the offsite emergency response organizations. Notification is not only important in initiating responses from offsite emergency response organizations but is also important in informing the population in the Emergency Planning Zone. For planning purposes the NRC has established four categories of emergencies and the levels

of response that must be made for each. These categories are:

1. Unusual Event
2. Alert
3. Site Area Emergency
4. General Emergency

Only for a General Emergency would protective actions such as sheltering or evacuation be required of the public. In order for there to be a declaration of a General Emergency, events must be in progess or have occurred which involve actual or imminent substantial degradation or melting of the reactor core.

2.2 The Roles of Government Agencies

At the federal level, there are many agencies with supporting responsibilities during an emergency at a nuclear power plant. The NRC is the cognizant federal agency responsible for coordinating technical aspects of the federal response, while FEMA coordinates the non-technical offsite aspects.

The Federal Radiological Emergency Response Plan (FRERP) can be activated if the state or local authorities request assistance from the federal government. The FRERP involves the combined capabilities of twelve federal agencies. Some of the agencies supporting the FRERP include the The Department of Energy (DOE), Department of Health and Human Services (HHS), Environmental Protection Agency (EPA), Department of Transportation (DOT), and U.S. Department of Agriculture (USDA). The FRERP has been fully exercised during actual plant specific drills.

State and local agencies are the primary points of contact in dealing with the health and safety of their citizens. In meeting these responsibilities they ultimately determine and implement the protective action requirements that the public should take, based upon recommendations from the utility and state and local offsite dose assessment agencies. It is the responsibility of state and/or local government decision-makers to adopt a course of action, and take the necessary alert and notification steps to inform the public of appropriate measures.

2.3 Basis of the EPZ

The 10-mile EPZ was established in 1978 on the basis of a major analysis of potential reactor accidents at nuclear power plants. The NRC's Reactor Safety Study (WASH-1400[8]), completed in 1975, was the most comprehensive analysis of the probability and potential consequences of reactor accidents of its time. Many of its results continue to be reaffirmed by more recent studies.

The NRC, in conjunction with EPA, evaluated the technical basis for emergency preparedness around nuclear power reactors using the WASH-1400 estimate of reactor risk. The two agencies published their findings in NUREG-0396. NUREG-0396 established a 10-mile radius plume exposure planning zone because it is unlikely that any immediate protective actions would be required by the public outside that area.

2.4 Adequacy of the 10-Mile EPZ

In the 10 years since the EPZ was established, a significant amount of new scientific and technical information has been developed. These data[9] indicate that far less radioactive material would be released during severe nuclear power accidents than previously assumed for most accident

sequences (see Appendix, Page A-11, Sec. 3.1). This means that the offsite consequences of a nuclear power plant accident would be considerably less severe than was assumed previously. Similarly, the extent to which protective actions would need to be taken in an emergency has been overestimated. Nonetheless, to date, these findings have not been incorporated into emergency planning policies. They do, however, provide assurance that all emergency responses -- including the Graded Response -- that are based on earlier studies and other early analyses are adequate.

2.5 Implementation

Emergency plans are designed to assist any area within the EPZ should there be a severe nuclear accident. All EPZ areas fall within the plan because it can not be known, before an emergency, which direction the windborne radioactive plume might travel during the time of an accident.

Planning to protect any area within an EPZ does not mean that all areas would be radiologically affected should an accident occur. Only a limited portion of an EPZ could be affected in a single accident. Planning to protect any area within an EPZ does not mean that the same level of emergency resources would or should be deployed to all EPZ areas during an actual accident situation.

Emergency planning regulations and regulatory guidance have recognized how rapidly the dose rate from releases of radioactive material would decrease within the first 2 miles. These regulations also reflect the fact that this radioactive material would travel in a windborne plume. Radiation levels, and therefore risks, are not uniformly distributed throughout the EPZ. Emergency responses which truly concentrate on those who are at risk are similarly not uniformly distributed

throughout the EPZ. An example of this is the guidance given in the NRC's Office of Inspection and Enforcement Information Notice No. 83-28. Here, the response to a General Emergency is the recommendation to initially shelter and, if warranted, evacuate an area of 2-mile radius near the plant and in the downwind direction out to 5 miles. This application has been known as the "keyhole" application. Not only should emergency responses differ from one location to another within an EPZ, the importance of taking timely protective actions also differs. Emergency planning therefore concentrates on expeditious protective actions near the damaged plant.

2.6 Misperceptions

Although the above basic emergency response principles are well understood by many emergency planners, important misperceptions persist elsewhere. The increased attention to emergency preparedness at nuclear power plants in recent years has led to a common misperception by some that emergency plans call for automatic evacuation of the entire 10-mile EPZ.

This confusion has been compounded by certain emergency drills which have been premised on the evacuation of the entire EPZ or governmental requirements to demonstrate plans and resources capable of simultaneously evacuating the entire EPZ. Information that nuclear utilities are required to distribute annually to people living within the EPZ may also foster misunderstanding. This material tells people that they may be asked to leave their homes and provides evacuation routes if such an action is required. Because of this, people can be left with the impression that nuclear power plant accidents require immediate large-scale evacuations. It can be speculated that some people incorrectly visualize nuclear accidents as rapidly spreading contamination in all directions.

It is important to correct these misperceptions. Not only is it a financial and psychological burden on the public, a massive evacuation of the entire 10-mile EPZ unnecessarily increases the risk to those closest to the plant. If evacuation is to be done, then it is far more protective to utilize the Graded Response. This preferred evacuation response is described in the next section.

3.0 THE GRADED RESPONSE

The Graded Response is an alternative to automatic large-scale evacuation. It allows emergency response organizations to focus resources on the members of the public most at risk, to tailor protective actions to the specific conditions being faced, and to implement them in a logical, manageable sequence. This provides greater protection to the population throughout the EPZ and much greater flexibility than a mass evacuation response.

3.1 Strategy

When officials determine that circumstances at a nuclear power plant, such as an anticipated or actual radiological release, warrant evacuation of the nearby public, they should take the following steps:

1. Notify the public to evacuate an inner zone near the plant of about 2 miles in radius while advising others within the EPZ to take shelter and wait for additional instructions via the radio, television or other means of communication.

2. Evaluate the findings of radiation monitoring teams and/or other data to determine the direction and speed that the radioactive plume (if any) is traveling, and the deposition of radioactive material on the ground and other surfaces.

3. Notify sheltered people in the EPZ to relocate out of areas downwind of the plant, if the above offsite monitoring surveys and/or other data reveal that they are or are expected to be in areas of ground contamination with unacceptably high dose rates.

With this strategy, the immediate action within the inner zone would involve a relatively small number of people.Nuclear power plants are typically located in sparsely populated areas. The total area within a 2-mile radius -- which includes the the plant site and usually a body of water -- is only 4 percent of the area of the entire EPZ. As a result, the average number of people within 2 miles of a nuclear power plant is only about 1 percent of the EPZ population[10]. Accordingly, assisting the public in its evacuation of the inner zone is much more effective for emergency officials and their manpower and communications resources than immediate full-scale evacuation of the entire EPZ. As a result, the coordination, logistics, traffic flow, and other activities associated with a large-scale evacuation would be vastly reduced. The amount of time required for the people most at risk to relocate would be significantly shortened.

For those people in the inner zone who in some unlikely event were evacuated, it would only be necessary for them to move a few miles over normally familiar territory to assure their safety. Sheltered people in the outer zone who were in the plume pathway and were relocated on the basis of radiation surveys, would also only have to travel short distances. Relocation would generally take place in a direction perpendicular to the plume pathway. Since plume widths are narrow, relocation distances and times would be short (See Figure 7, Appendix B).

Note that the actual evacuation or relocation of the public would be largely carried out by the public itself based on the information provided by the emergency response organization. Direct assistance would be provided to special members of the public, such as those who are transportation limited.

3.2 Flexibility

Scientific studies, regulatory guidelines, experience with accidents and exercises, and basic logic have identified the importance of flexibility in emergency responses. In the event of a severe nuclear power plant accident, many factors must be considered that cannot be predicted with precision. These include the magnitude of the release of radioactive material, the amount of time available to implement protective action recommendations, the direction and speed of the wind, the time of day, current traffic patterns, and the weather. One of the most important ancillary benefits of Graded Response, then, is its flexibility.

Immediate evacuation of an entire or large portions of the EPZ is not only an inappropriate evacuation response, it can also pose unnecessary demands on emergency resources, traffic control and communications even under ideal circumstances. Bad weather -- heavy rain or snow -- or even nighttime conditions could unnecessarily increase the burden of these demands. Indiscriminate evacuation could also result in the movement of people who were not in areas affected by radiation into areas that were. It could lead to needless movement of people, and thereby impose unnecessary risks.

The strategy of the Graded Response recognizes that actions should be tailored to the particular nature of the danger. Public officials could take immediate action to protect the population most at risk -- nearest the plant -- and then have time to determine what additional actions -- if any -- should be taken. If radioactive contamination of the ground warranted additional relocation of people who were sheltered, there would be time to do so.

This flexibility would also helpful for site-specific distinctions. It would allow more consideration to be given to such factors as roads or highways that might be in the immediate path of the plume, and would provide time and opportunity for decisions that could adapt protective actions to the specific conditions in which they would have to take place.

Since people on an annual basis are indoors about 85 percent of the time, taking shelter would not disrupt many people[11]. Those people taking shelter during a Graded Response would have access to TV and/or radio, so they could receive news broadcasts about the location of contaminated areas and the need for further actions. These broadcasts would also reduce the likelihood of inadvertent entry into such areas.

The Graded Response has other benefits. Plant operators would likely be able to terminate a serious accident or limit the releases of radioactive material to negligible quantities by maintaining containment integrity. In such cases, the Graded Response would have led only to evacuation of the 1 percent or so of the total EPZ population (those living in the inner zone nearest the plant). This would minimize the public's inconvenience. Such a response would not preclude subsequent optional actions by emergency response officials. For example, for many core melt accidents containment integrity might be maintained for a long period of time or permanently. During this time period, if the termination of the accident were uncertain, recommendations such as to evacuate limited areas beyond the inner zone, might be made.

Similarly, the Graded Response permits flexibility in the outer zone. Sheltered persons in this zone need only be relocated from areas that radiation surveys had shown unacceptably high dose rates. For smaller releases this would

involve a smaller area to be relocated than for larger releases. Conversely, the Graded Response process of "measure" and "relocate" could be extended on an optional basis. This might be done in some cases in implementing Environmental Protection Agency plume protective action guidelines (PAG's).

Thus, the Graded Response has the flexibility to match the emergency response to the protective needs as dictated by specific accident conditions.

3.3 Effectiveness

Resources would be utilized more efficiently in the Graded Response. By focusing resources on those who are truly at risk, evacuation could proceed promptly, contaminated areas could be identified readily, and the unnecessary movement of unaffected people would be minimized. Inadvertent entry into contaminated areas would also be minimized. Communications would be simplified, as would be traffic control and the ability to help individuals who need special assistance.

All of the above attributes are consistent with the very limited consequences calculated in various Graded Response studies. As described more fully in the Appendices, full implementation of the Graded Response is expected to lead to a near zero risk of having an early fatality. This is true even at highly populated sites and even when very severe releases of radioactive material are assumed. Additionally, NRC studies of an actual high population site show much greater public protection, compared to a mass evacuation response, by using the Graded Response. Specifically, there was about a 25,000-fold reduction in the calculated early fatality risk using the Graded Response compared to a large evacuation response.

3.4 Technical and Regulatory Bases

The technical basis for the Graded Response is scientifically conservative. It does not take credit for the fact, as recent experiments and studies have demonstrated, that the amount of radioactive material that might be released from a nuclear power plant accident would be far less than has been assumed in the past. Additionally, it does not take credit for the fact that the material released is likely to enter the environment as a buoyant plume. This would further limit its consequences.

The Graded Response strategy does not assume a reduction in the size of the EPZ. Thus, it does not require any changes in current NRC or FEMA regulations. It will, however, require a change in current exercise philosophy, such as demonstrating that resources are available to simultaneously evacuate the entire EPZ.

4.0 CONCLUSIONS

A large accident at a U.S. nuclear power plant that results in a significant release of radioactive material into the environment is extremely unlikely. Nevertheless, should such an accident occur, prior planning for strategies and specific actions to be taken by the plant operator and the offsite emergency response organization is important to minimize its impact on the population.

Emergency preparedness for nuclear power plants has been significantly expanded and refined over the past decade. But there is a widespread misperception that the required protective action response is large-scale evacuation of the entire or large portions of the EPZ. In fact, a simpler alternative strategy -- the Graded Response -- is more manageable, more flexible, and more effective in minimizing the effects of severe accidents. These conclusions are valid even using the assumptions of early reactor safety studies that have since been shown to have greatly overestimated the amount of radioactive material that might be released to the environment.

The Graded Response is a flexible strategy that enables emergency planners and decision-makers to deal with a broad spectrum of severe accidents, focus emergency resources on people who are at greatest risk, and match the response to the actual need. In terms of public protection and manageability, the Graded Response is the preferred evacuation strategy for nuclear emergency preparedness.

TECHNICAL BASIS FOR THE GRADED RESPONSE

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APPENDIX A

TECHNICAL BASIS FOR THE GRADED RESPONSE

It is important to have a firm technical basis for emergency preparedness in order to develop practical response strategies that maximize public protection. With such information in hand it is then possible to determine what actions and resources are needed to implement these preferred strategies.

1.0 HEALTH RISKS

As a first step in analyzing different emergency planning strategies, it is useful to separate nuclear accident health risks* into three principal groups:

1. Latent fatal cancer risks
2. Early injury risks
3. Early fatality risks

Societal latent fatal cancer risks from nuclear power plant accidents principally arise from long-term exposure to very low levels of widely dispersed radioactive material** (assuming interdiction actions have been taken to minimize food chain effects). Studies have shown that the societal latent fatal cancer risk would increase only by a small increment (far less than one tenth of 1 percent) above the normal non-nuclear fatal cancer rate of about 16 to 18 percent even if there were a severe release of radioactive material. This small increment would likely be less than the year-to-year statistical variation in the normal societal latent fatal cancer rate and would therefore be too small to be detected. Most important, keeping this societal latent fatal cancer increment to such a

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*The threshold for early fatalities, assuming minimal medical treatment, is usually taken as 200 rads (rems). A more precise relationship between radiation exposure and the probability of an early fatality is presented in Figure 1. Early injuries are often considered to have a threshold value of about 50 rems.

**The amounts of radioactive material released into the environment from a damaged nuclear power plant is called the source terms.

small value does not depend upon taking emergency protective actions, such as sheltering or evacuation, during the time a radioactive plume is being released from a damaged plant.

Certain people near the damaged plant may have individual increases in their latent fatal cancer risk that would be higher than the societal value. Their individual latent fatal cancer risk might increase by approximately 1 percent to 2 percent per 100 rads of whole body exposure. Emergency responses taken to reduce the early health effect risks, described later, would also be useful in limiting this individual latent risk. In any case, an individual's latent fatal cancer risk cannot have an increment of more than several percent above background values from a nuclear plant accident. As radiation exposure increases over 200 rads, the individual's fatality risks quickly shift from latent to early (See Figure 1).

Since nuclear accident latent fatal cancer risks for both the individual and societal as a whole are naturally small, it is the early health effect risks that could be most profoundly affected by emergency planning. Individual early fatality and societal latent fatal cancer risks have opposite geographic and temporal distributions. Whereas the societal latent fatal cancer risk is widely dispersed and radiation exposure would slowly accumulate over many years or even decades, the individual early fatality risk is geographically very short ranged and exposure time periods of even a few hours can be important. Therefore, in order to develop an emergency response strategy to minimize early health effect risks, particularly the early fatality risk, it is important to understand how this risk is distributed as a function of distance, the importance of time of exposure, and the relative merits of evacuation versus sheltering. The impact of distance is discussed below, while timing, sheltering and evacuation are discussed in Section 2.0, ANALYSES.

Release of radioactive material from a damaged nuclear power plant would travel in a windborne plume similar to what one observes while watching the smoke from a smoke stack. The further from the point of release, the more dilute the plume becomes, with a corresponding increase in the size of the plume. The degree of dilution of the plume is largely dictated by plume buoyancy, meteorological conditions and local topography. Figure 2 is a representative plot of how the relative dose rate decreases with distance. Note that the dose rate decreases about 90 percent between one-half mile and two miles.

Examination of the dose rate versus distance distribution curve (Figure 2) leads to the conclusion that, because of dilution, the area of greatest risk is near the plant. This conclusion is further reinforced by a second distribution: early fatality risk versus distance. Small decreases in radiation dose (dose rate multiplied by the time of exposure) can result in very large reductions in the early fatality risk. For example, using the curve in Figure 1, a decrease from 400 rads of exposure to 200 rads of exposure, a factor of two, yields a decrease in the mortality factor from 0.800 to 0.005. A 2-fold reduction in dose results in a 160-fold reduction in the mortality rate, in this example. This means that the early fatality risk decreases far more steeply with distance than dose rate does with distance. Either of these distributions leads to the conclusion that the area of greatest risk is near the plant, with the early fatality risk versus distance distribution making this point even more emphatically.

2.0 ANALYSES

As discussed above, early fatality risks naturally decrease rapidly with distance from the plant because of dilution. Supplementing this natural protection, there are protective actions, such as sheltering and evacuation, that people can take to further reduce their risks. Numerous analyses have been made which account for these protective actions. Such analyses are useful in developing optimum emergency planning strategies. Three such studies are discussed below. All three of these studies are based on assumptions of unrealistically large releases of radioactive material.

2.1 DOE Site Independent Analyses

In 1984 the Department of Energy (DOE) conducted a site independent study[12,15] of the relative merits of sheltering and evacuation. A uniform population distribution was assumed. Figure 3, based on CRAC code calculations, plots the mean individual early fatality risk versus distance for an assumed SST-1[13] release (see Table 1). Three of the lines in Figure 3 are for evacuation responses where the time to initiate evacuation differs from case to case. The other two cases examine sheltering, one for 4 hours and the other 8 hours. The 4- and 8-hour sheltering periods were assumed to begin at the time of plume arrival and end when the individual was relocated out of the plume deposition area.

Several conclusions can be drawn from these analyses:

A. The individual mean early fatality risk decreases very rapidly with distance.

B. Timing is important. The individual mean early fatality risk is larger when evacuation is delayed. This can be observed by comparing the 1, 3, and 5 hour evacuation delay time* curves.

C. Sheltering, followed by relocation out of contaminated areas within a reasonable time period, is an effective response to large releases. Sheltering is more effective than evacuation, except when evacuation has a short delay time or occurs prior to the release of radioactive material. The sheltering curves in Figure 3 are based on shielding factors typical of many structures in the northeastern section of the United States (See Table 1).

2.2 NRC Site Specific Analyses

The DOE analyses, above, inferred that a combination of evacuating the inner 2 miles or so around a nuclear plant and sheltering in the remaining 2 to 10 mile annulus in the emergency planning zone should result in low early fatality risks. After about 2 miles, with northeastern type structures, the risk to a sheltered person is very low even if sheltered for eight hours after plume passage. The smaller the inner evacuation zone, the more rapidly it could be evacuated. At about 2 miles, it appears that a good balance would be struck between rapidly evacuating the inner zone and providing adequate sheltering protection in the outer zone.

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*Delay time is defined as the time between issuing a public warning and the time when people begin to evacuate. In these analyses, warning was assumed to be issued 1/2 hour prior to the release of radioactive material.

The next step is to determine if the insights gained from the DOE analyses with its uniform population distribution apply to actual sites where the population distributions are non-uniform. A U.S. Nuclear Regulatory Commission (NRC) study[14] of the effectiveness of two different emergency response strategies at a northeastern high population site is instructive. Table 2 reports NRC results which compare a large evacuation strategy to the Graded Response strategy. Large evacuations are modeled as 30 percent, 40 percent, and 30 percent of the total population within the EPZ evacuating with 1, 3, and 5 hour delay times, respectively. It is assumed that prior to evacuation the population did not respond to the accident and acted as they normally do, i.e., about 85 percent of the time indoors and 15 percent outdoors.

In the Graded Response strategy, greatest emphasis is given to those closest to the plant to have them take an emergency response as soon as possible. The NRC's Graded Response analysis assumed a timely, 10 mph evacuation of the entire population within an area, 2 miles in radius, immediately next to the plant. This inner zone was surrounded by an outer zone where sheltering was assumed. Sheltered people in the plume deposition area were assumed to stay sheltered for four hours after the plume arrived and then relocated out of the contaminated area. Except for the differences in these emergency response strategies, all other aspects of these NRC analyses -- the meteorology, demography, the computer code used, etc. -- were identical.

Assuming an SST-1 source term, these NRC CRAC code analyses calculated a 25,000 fold reduction in the mean early fatality risk -- 32.8 vs. 0.0012 -- for this site, if the Graded

Response were fully utilized instead of massive evacuation. There were also large reductions in the calculated maximum (or peak) number of early fatalities and fewer early radiation injuries. The Graded Response, which would focus the emergency workers on those who were truly at risk, would therefore be far more efficient than a larger evacuation. These same NRC analyses calculated that, when combined with a very small reduction in the SST-1 source term (a factor of 2, but not reducing the noble gas releases), zero early fatalities would be expected should the Graded Response be fully used.

2.3 EPRI Site Specific Analyses

In the past two years, the Electric Power Research Institute (EPRI), has also used the CRAC code to demonstrate the effectiveness of the Graded Response[15]. Like the NRC, it examined a northeastern high population site, albeit a different one. Its results are consistent with the trends seen in the earlier NRC site-specific analyses and the site-independent DOE analyses. EPRI assumed a PWR-2 source term*, which is similar to an SST-1 source term. As discussed before, releases of radioactivity as large as PWR-2 or SST-1 would be very rare, if not unattainable.

*Reference 19, Tables 1a and 1b.

The table below is derived from the EPRI analyses:

IMPACT OF DIFFERENT EMERGENCY RESPONSES

High Population Site/PWR-2 Release/Six Hours of Exposure

	Emergency Response	Mean Number of Calculated Early Fatalities	Mean Number of Calculated Early Injuries
1.	Normal Activities	466.00	1550.
2.	All Sheltering (0-10 Miles)	22.50	465.
3.	The Graded Response (10 mph evacuation of inner two mile zone beginning at time of release)	0.22	126.

Normal activities were modeled as before, with 85 percent of the people indoors and 15 percent outdoors. In this EPRI analysis, 6-hour exposure times were assumed. A total lack of response (normal activities) for 6 hours after a severe release of radioactivity might be considered an extraordinary failure in the emergency response process. Even in this extreme situation, less than 2 percent of the approximately 270,000 people within the EPZ at this site might become early fatalities. This limited impact is largely due to the inherent risk reduction associated with plume dilution, discussed earlier. Note that merely taking shelter provides a 20-fold

reduction in the number of calculated early fatalities relative to normal activities. Still further improvements are obtained when the Graded Response is used. Assuming a 10 mph evacuation speed for the inner 2 miles and 6 hours of sheltering in the outer zone, another 100-fold reduction in the early fatality risk is observed. In summary, natural effects limit the early fatality risk to about 2 percent of the EPZ population. The Graded Response can further reduce this percentage approximately 2,000-fold, that is, effectively a zero early fatality risk.

Note that both the EPRI and NRC analyses show that those protective actions taken to minimize the early fatality risk will simultaneously reduce the early injury risk (and the individual latent fatality risk as well).

2.4 Summary

Based on the DOE, NRC, and EPRI studies it can be concluded that the Graded Response, i.e., a response that emphasizes the use of sheltering beyond 2 miles, would be highly effective in minimizing health consequences from nuclear accidents even if inordinately large releases of radioactive material are assumed. This reassurance is in addition to the NRC studies indicating that the Graded Response would be more effective than a large evacuation response.

3.0 CONSERVATISMS

There are a number of major conservatisms utilized in the analyses supporting the Graded Response. This strategy accepts the conservative assumption that emergency planning is necessary despite the extremely small probability of a severe release of radioactive material. It also accepts the 10-mile radius for the EPZ, despite evidence indicating that such an area is much larger than necessary. In this section two other major conservatisms are discussed -- source terms and plume buoyancy.

3.1 More Realistic Source Terms

The analyses in Section 2.0 are based on ultra-conservative source terms, such as the SST-1 and PWR-2 source terms. Many recent, more realistically calculated source terms, such as those that appear in NUREG-1150[9], are often 10 to 100 times smaller than the assumed SST-1 source term, especially in those cases where the containment fails many hours after the reactor is damaged. Further, data gathered on the Chernobyl accident[16,20] indicate that the release of iodine and tellurium, two elements whose radioactive isotopes dominate the early fatality risk in severe accidents, were smaller than SST-1 values during the critical early phases of the accident. Analyses based on smaller source terms result in smaller calculated health risks, particularly the early fatality risk. The impact of reducing the SST-1 source term by only a factor of 2 (excluding any reduction in assumed radioactive noble gas releases) can be appreciated by comparing the calculated early fatality and early injury values in the left and right columns of Table 2. Further, when source terms are smaller, the distance over which early fatalities may occur is shortened. This can be seen by comparing Figures 3 and 4. In the latter

case a source term of 1/3 SST-1 was assumed. Therefore, smaller source terms provide a technical basis for moving the boundary between the inner and outer zones closer to the site.

An analysis shown in Table 2, based on a combination of the fully utilized Graded Response and a factor of 2 reduction in the SST-1 source term (excluding noble gases) resulted in no calculated early fatalities. If the less effective large evacuation response was assumed instead of the Graded Response, then no early fatalities would be expected if the source term, other than noble gases, were approximately one sixth that of the SST-1. If the size of the source term were about 30 to 50 times smaller than the SST-1 source term, no early fatalities would be expected beyond 1 to 2 miles even if no emergency response was taken.

Therefore use of more realistic source term analyses virtually eliminate the calculated risk of early fatalities for many severe nuclear accidents as well as causing a reduction or elimination of the number of calculated early injuries. Smaller source terms also result in fewer calculated latent health effects and a decrease in off-site economic consequences[17].

The Graded Response analysis takes no credit for such smaller, more realistic source terms and is, therefore, conservative.

3.2 Plume Buoyancy

For many serious nuclear accidents, the containment would not fail and off-site consequences would be negligible. Those rarer accidents that would cause the containment to fail after many hours would likely have small source terms and would not produce severe consequences for the reasons stated above. An

accident that might cause the containment to fail promptly (See Table 1) would be a very rare event and would represent the most serious challenge to the emergency forces. Such a rare accident would likely have significant internal heat energy, and therefore its radioactive plume would likely be buoyant. Recent (1987) Sandia National Laboratory CRAC code studies[18], assuming SST-1 releases, have examined the effects of plume buoyancy. The overall effects of accounting for plume buoyancy are to lower the calculated early health effect risks and to significantly extend the time that sheltering would be an effective response, even very close to the plant.

Many earlier consequence analyses conservatively assumed a cold or non-buoyant plume. When a plume is buoyant there would be a lower concentration of radionuclides, compared to a cold plume, in the first 3 miles or so near the plant. Lower concentrations mean that it takes longer to reach a particular level of radiation exposure. Therefore, these recent Sandia efforts indicate that plume buoyancy would appreciably extend the time it takes sheltered people within the first few miles near the plant to receive significant levels of radiation exposure. For example, using Table 1 shielding factors, a person sheltered 1 mile from the point of release of an SST-1 source term, under conservative weather conditions that result in very concentrated plume, (F stability and a wind speed of 5 meters/second) would receive 200 rems of exposure in about 1.5 hours in the non-buoyant case. More than 16 hours would be required when buoyancy is accounted for (See Figure 5).

3.3 <u>Summary</u>

Because the Graded Response gives no credit for either plume buoyancy or more realistic source terms -- each of which would reduce or totally eliminate certain calculated health risks -- the technical basis for the Graded Response is very conservative.

4.0 OTHER CONSIDERATIONS

4.1 Sheltering/Inner Zone Considerations

Different structures can have different radiation shielding capabilities. Variations in shielding capability may occur within a single EPZ and differences exist from one region of the country to another. The shielding factors (the ratio of the interior to exterior doses) used in the DOE analyses are given in Table 1 and are typical for homes in the northeastern section of the United States. The NRC and EPRI studies use similar northeastern shielding factors. Where other sites have structures with less shielding capability[19], this can be compensated for by increasing the size of the inner evacuation zone, i.e., sheltering would begin where dose rates would be lower. Analyses indicate that compensating for smaller shielding capabilities would probably not increase the radius of the inner zone beyond three miles. Figure 6 and the data in Table 3 can be used to adjust the size of the inner zone to compensate for variations in shielding factors. Like the basic concept of the Graded Response, this approach to establishing the inner boundary is conservative in that it does not take credit for the inner zone shrinking effects of smaller source terms or for the sheltering enhancement effects of plume buoyancy.

Site specific analyses may also result in a somewhat non-circular inner boundary, but approximately 2 to 3 miles in radius. For example, if a highly populated, well sheltered, area falls near the inner zone boundary, it probably is more effective to place this populated area in the outer zone. Conversely, the otherwise circular inner boundary could be extended somewhat to encompass easy-to-evacuate, low population density areas.

suggest a different sequence. This, again, applies the principle of concentrating one's emergency forces on the area of greater risk. Although relocating people from multiple areas would represent an increase in effort, the overall radiation effect would generally be to lower early health risks. The greater the distribution of a fixed amount of radioactive material, the lower the average concentration of this material. Lower concentrations (i.e., more dilution) lead to lower individual exposures which disproportionately decrease early fatality health effects (see Figure 1). Therefore, plume meander, much like plume buoyancy, generally lowers early health risks.

4.3 Public Conformance

In the Graded Response, typically 99 percent, or some portion thereof, of the EPZ population would initially be advised to take shelter, as appropriate. Although reviews of past emergencies reveal that during such times almost all people follow the instructions of their authorities, it is assumed here that some members of the public will choose to evacuate rather than shelter.

A high degree of public conformance to instructions (e.g., take shelter) is not a requirement for success in this emergency response. The impacts of excess evacuation, beyond that recommended by the authorities, is examined below for both the inner and outer zone EPZ populations.

With regard to the inner zone, this small population would be advised to evacuate promptly once the decision has been made to evacuate as a protective action. On the basis of this advice, and by concentrating emergency forces first on this limited group of people, this inner zone should be cleared quite quickly. Even at walking speeds (about 3 MPH) this inner

zone could be evacuated in a short time. To the extent that people in the outer zone would take shelter as recommended, road traffic should be below normal. It is highly likely that the inner zone would be largely evacuated as planned well before self-initiated outer zone evacuation, if any, might occur.

With regard to the outer zone, only the downwind portion of this area would be radiologically affected. People who were not at radiological risk and continued to shelter, if requested to do so, would not incur any radiation exposure. People who were not at radiological risk, yet nevertheless chose to evacuate, would not incur radiation exposure -- unless they inadvertently entered the plume deposition area. By determining the location of this deposition area and by disseminating this information via the media, as well as dispatching emergency workers to the contaminated area, inadvertent entry should be avoidable. Sheltered persons actually in the plume deposition area could relocate at their earliest convenience and need not await the arrival of emergency workers (assuming assistance isn't needed). The relocation of sheltered persons from the plume deposition area might also discourage inadvertent entry by evacuees who originated from areas outside of the plume deposition area.

Even if one assumes considerable excessive self-initiated evacuation and traffic congestion in the outer zone, it is only meaningful if this congestion occurs in the plume deposition area. While this is unlikely for the reasons given above, radiation exposure even under these conditions could well be limited. Since plume widths are usually narrow (see Figure 7), and dose rates are much lower in the outer zone (see Figure 2) and the emergency workers dispatched to the plume deposition area would assist in moving traffic along, total radiation exposure should be limited.

Therefore, although public conformance is expected and desirable, it is not mandatory to assure the effectiveness of the Graded Response.

TECHNICAL BASIS FOR THE GRADED RESPONSE

APPENDIX B

1.0 TABLES B-1

2.0 FIGURES B-4

3.0 REFERENCES B-11

4.0 ADDITIONAL INFORMATION SOURCES B-13

TABLE 1

A. ASSUMPTIONS EMPLOYED FOR DOE CONSEQUENCE CALCULATIONS

1. SST-1 Source Term

2. 10 miles per hour evacuation speed.

3. Normal activities assumed before evacuation with the following shielding factors:

Cloudshine factor	0.75
Groundshine factor	0.33
Inhalation factor	1.00

4. Shielding factors for sheltering:

Cloudshine factor	0.50
Groundshine factor	0.08
Inhalation factor	0.50

5.

Time of Release (hr)	1.5
Release Duration (hr)	2.0
Warning Time (hr)	0.5
Release Height (meters)	10.0
Release Energy	0

B. SST-1 SOURCE TERM

GROUP ELEMENT	RELEASE FRACTION
Xenon and Krypton	1.0
Iodine	0.45
Cesium	0.67
Tellurium and Antimony	0.64
Barium and Strontium	0.07
Ruthenium	0.05
Lanthanum	0.009

Source: Reference 13

TABLE 2
NRC SITE SPECIFIC ANALYSIS*

		SST-1				1/2 SST-1		
		Mean	99%**	Peak		Mean	99%**	Peak
Massive + Evacuation	Fatalities	32.8	1100.0	2160.0	Fatalities	8.64	200.0	2100.0
	Injuries	191.0	2700.0	8090.0	Injuries	55.8	1700.0	3280.0
Graded ++ Response	Fatalities	.0012	1.0	7.8	Fatalities	0.0	0.0	0.0
	Injuries	15.5	570.0	1200.0	Injuries	2.8	120.0	373.0

* Adapted from "A Perspective on Emergency Planning, Risk and the Source Term Issue", James Martin, USNRC, April 13, 1983 [Ref. 14].

** Consequences are equal to or below this value 99% of the time.

\+ In a massive evacuation model 30%, 40%, and 30% of the EPZ population are assumed to evacuate with 1, 3, and 5 hour delay times, respectively.

++ Inner 2 miles is evacuated promptly, with sheltering in the 2 to 10 mile annulus. If release occurs, persons sheltered in the plume deposition area would be relocated within four hours.

TABLE 3
REPRESENTATIVE SHIELDING FACTORS FOR SURFACE DESPOSITION

Structure	Representative Shielding Factor[a]	Representative Range
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: one story, less than 3 ft of basement, walls exposed	0.1 [b] 0.005 [b]	0.03 - 0.15 0.03 - 0.07
Two stories, less than 2 ft of of basement, walls exposed	0.03 [b]	0.02 - 0.05
Three or four-story strucutres 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

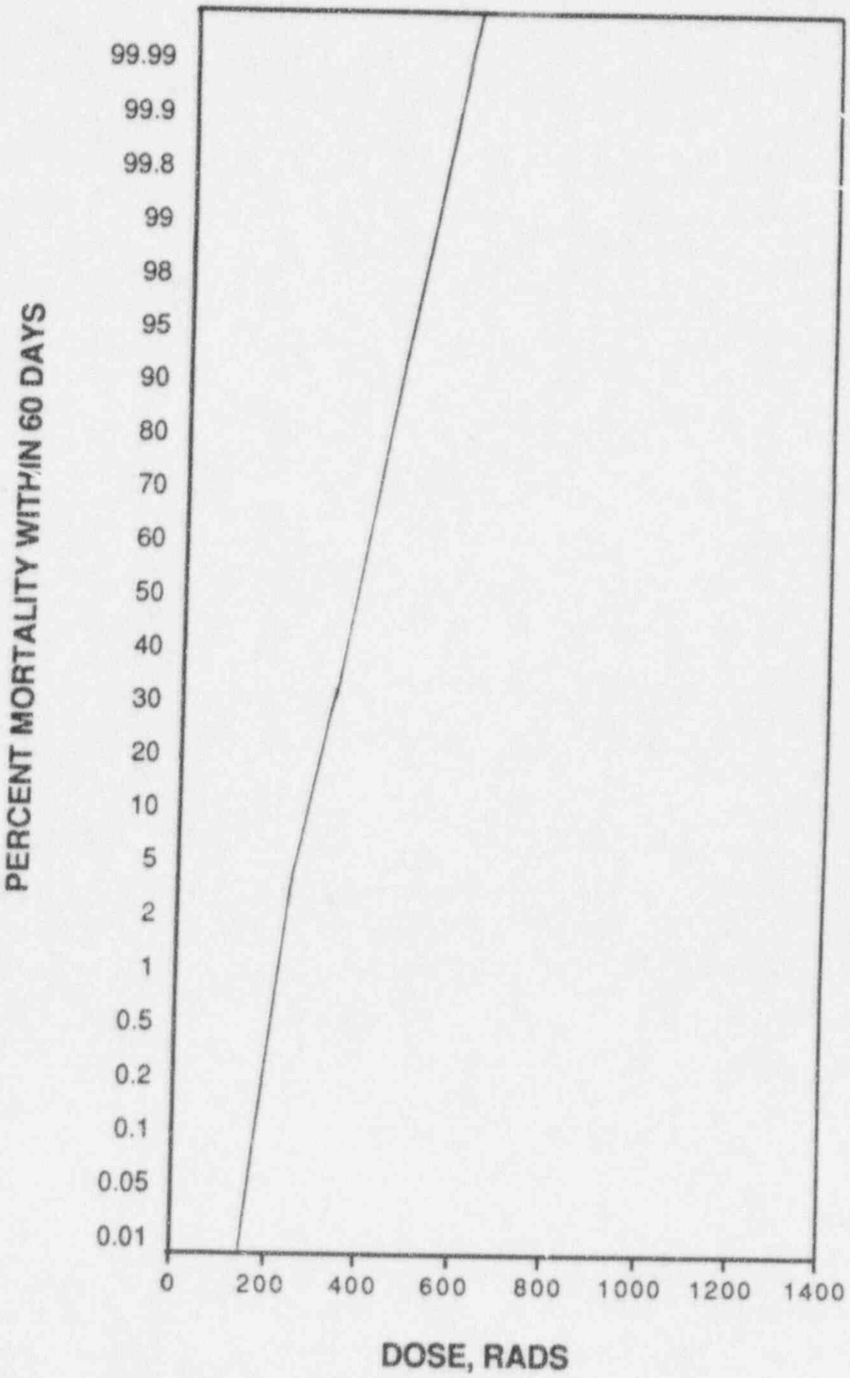
(a) The ratio of the interior dose to the exterior dose

(b) Away from doors and windows

Source: Reactor Safety Study, WASH-1400, NUREG 75/014, October 1975

Figure 1

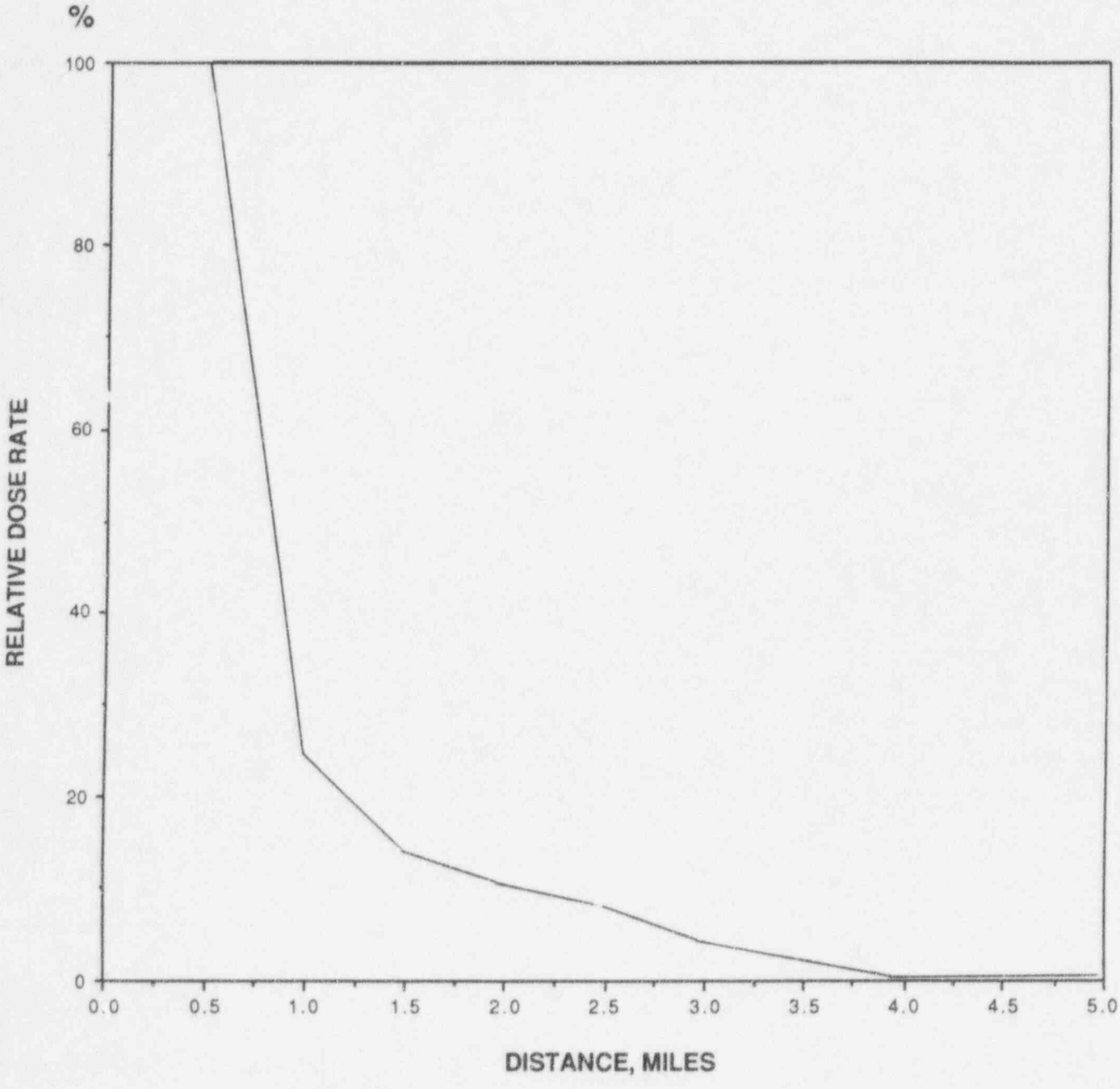
Estimated Dose-Response Curve with Minimal Medical Treatment



Reference: "Reactor Safety Study," WASH-1400, Figure VI 9-1

Figure 2

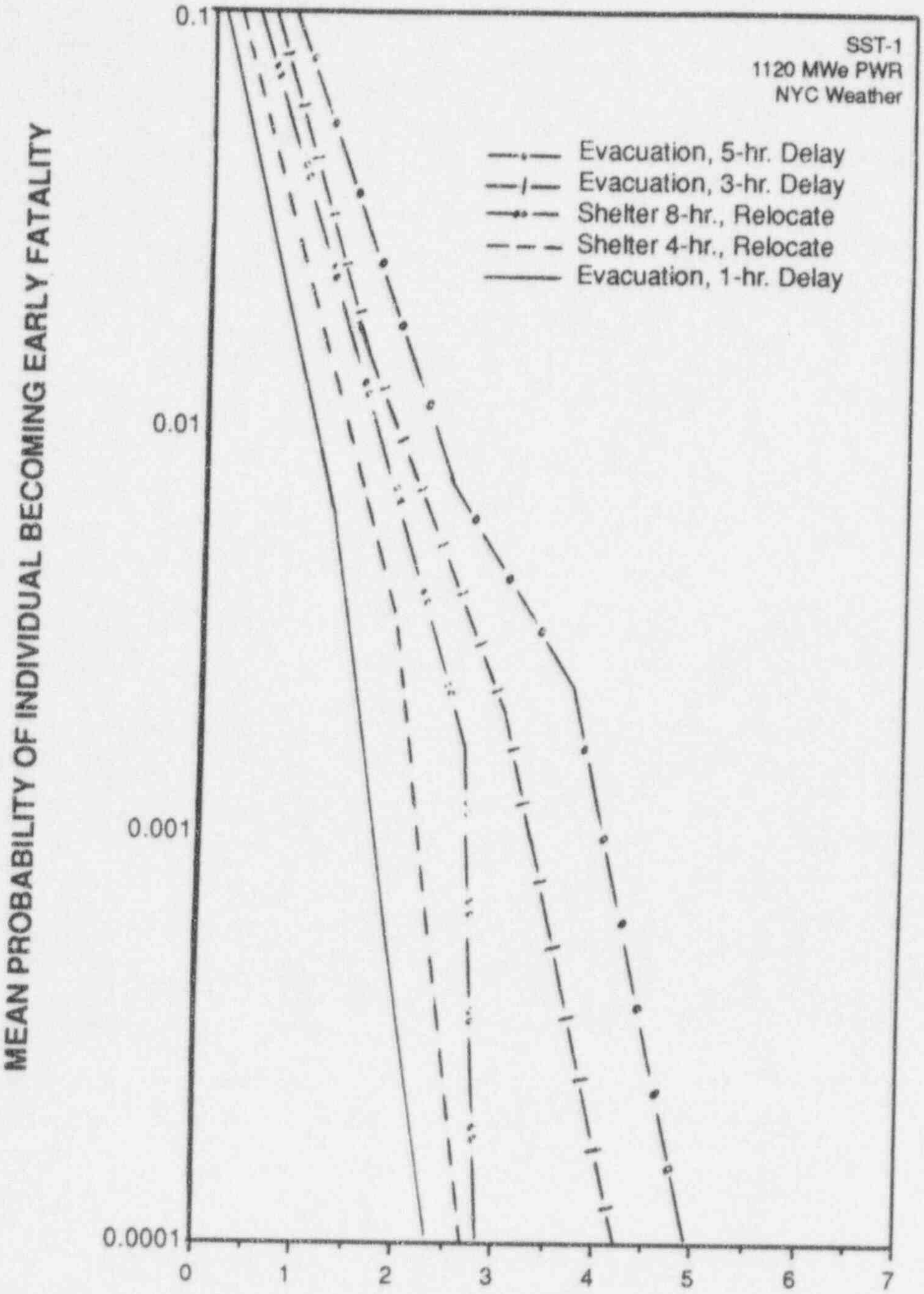
Relationship of Dose Rate and Distance for a Low Level Atmospheric Release



Source: "Objectives of Emergency Response and the Potential Benefits of Evacuation and Shelter," 1985, James A. Martin, Jr., USNRC, Washington, D.C.

Figure 3

DOE Analysis

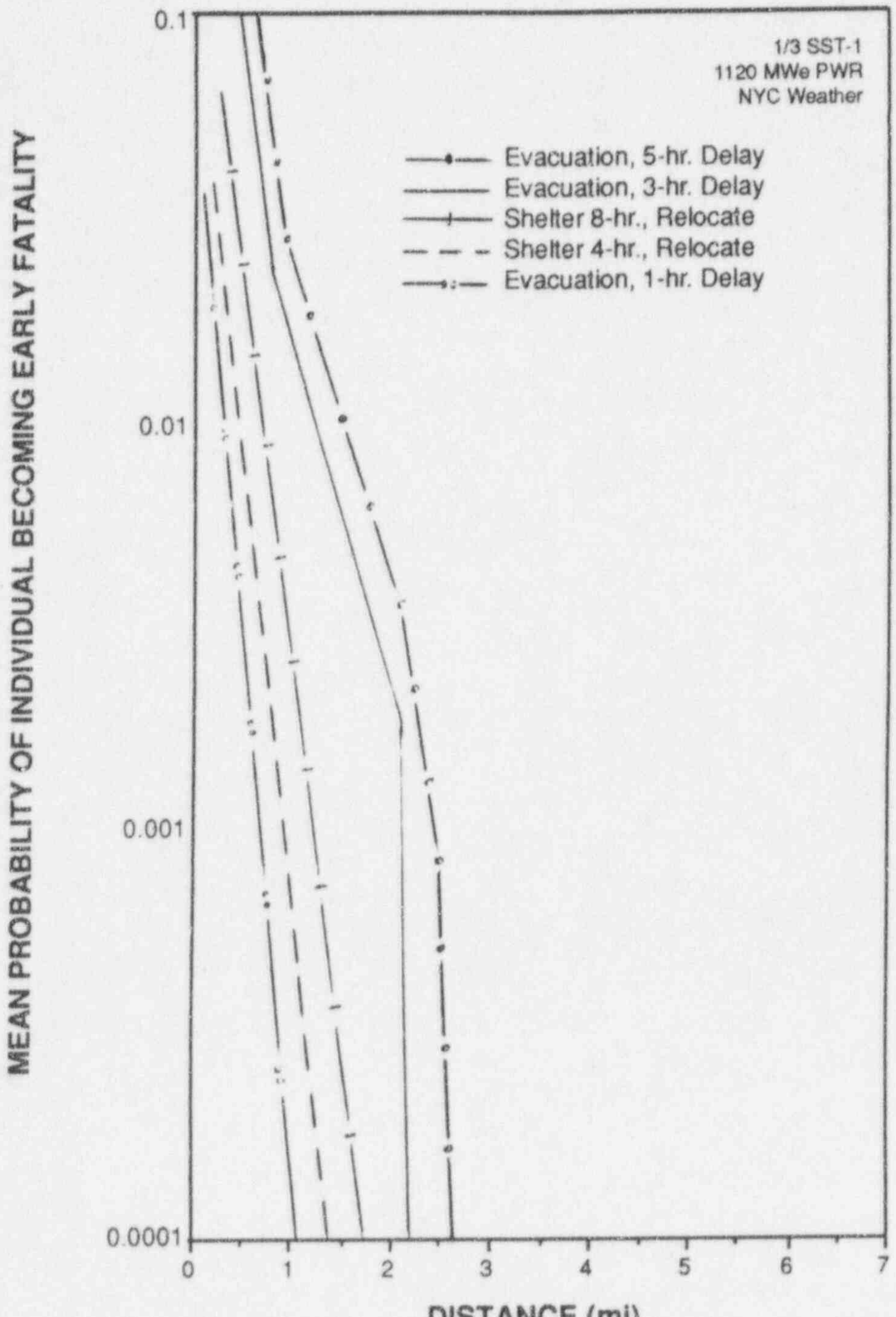


MEAN PROBABILITY OF AN INDIVIDUAL BECOMING AN EARLY FATALITY VS DISTANCE (SST-1)

Source: Reference 12

Figure 4

DOE Analysis

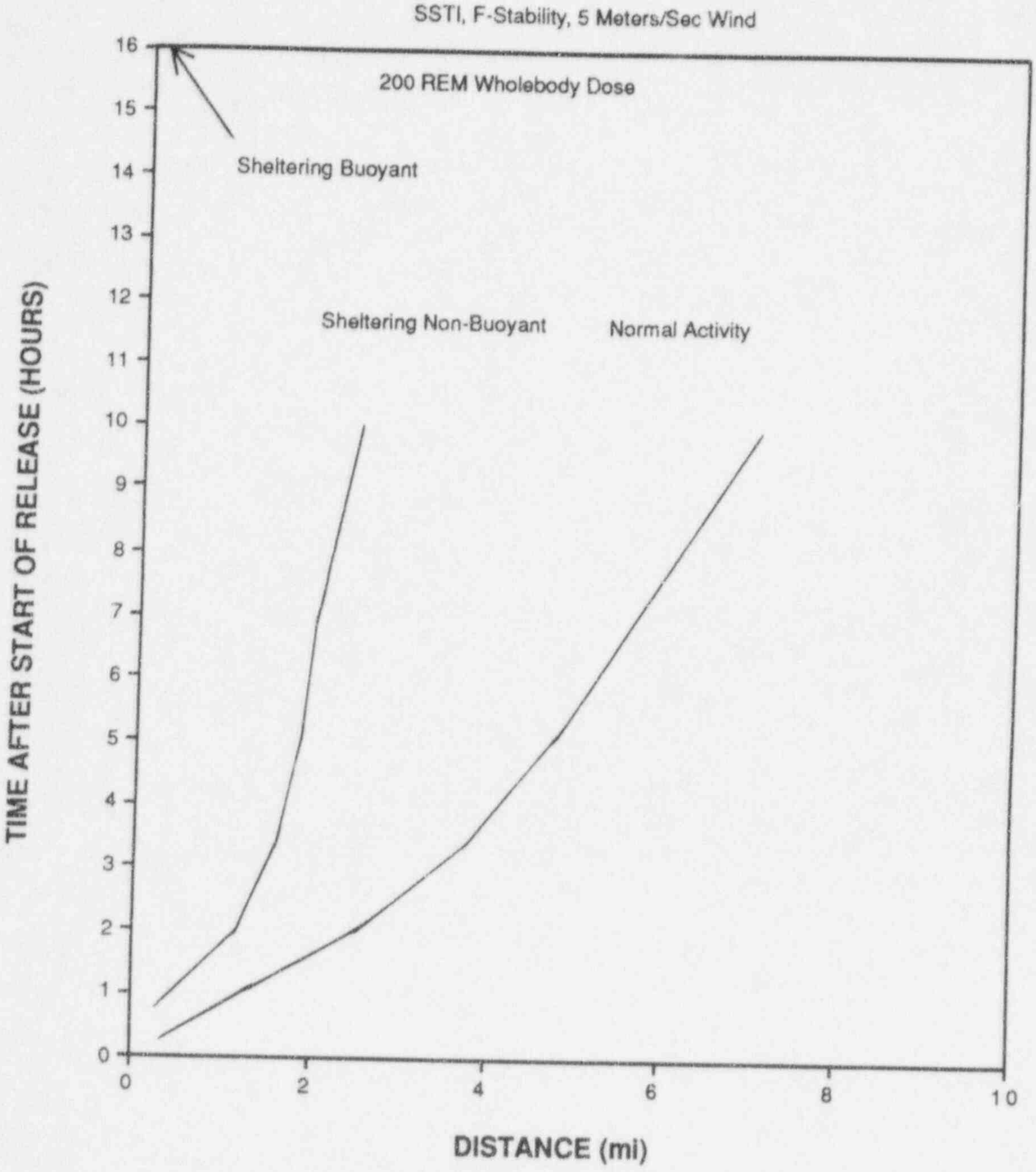


MEAN PROBABILITY OF AN INDIVIDUAL BECOMING AN EARLY FATALITY VS DISTANCE (1/3 SST-1)

Source: Reference 12

Figure 5

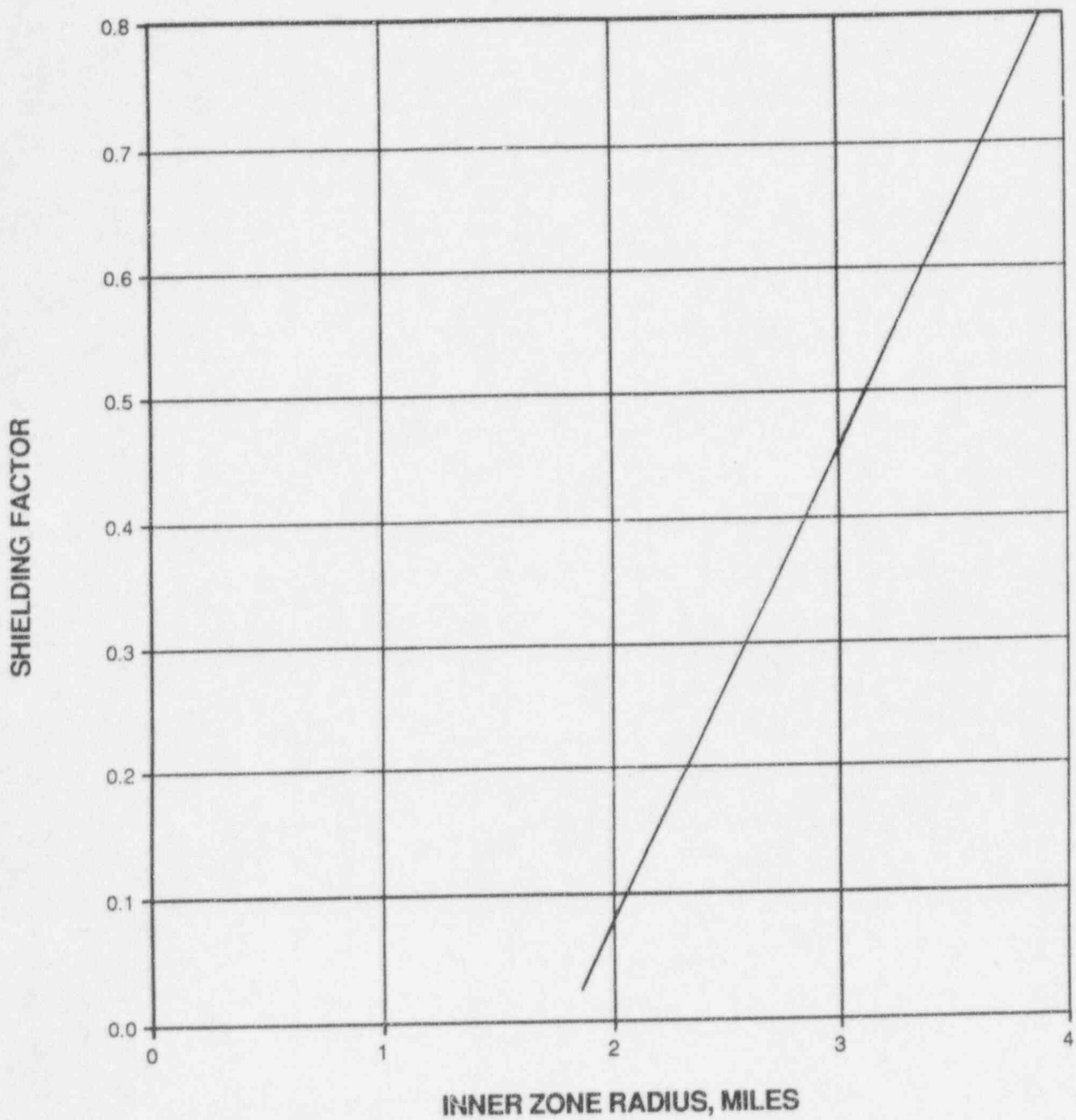
Impact of Buoyancy on the Time to Reach 200 REMs While Sheltered Northeastern Type Sheltering



Reference: Personal Communication from Dr. Lynn Ritchie, Sandia National Laboratories, February, 1988.

Figure 6

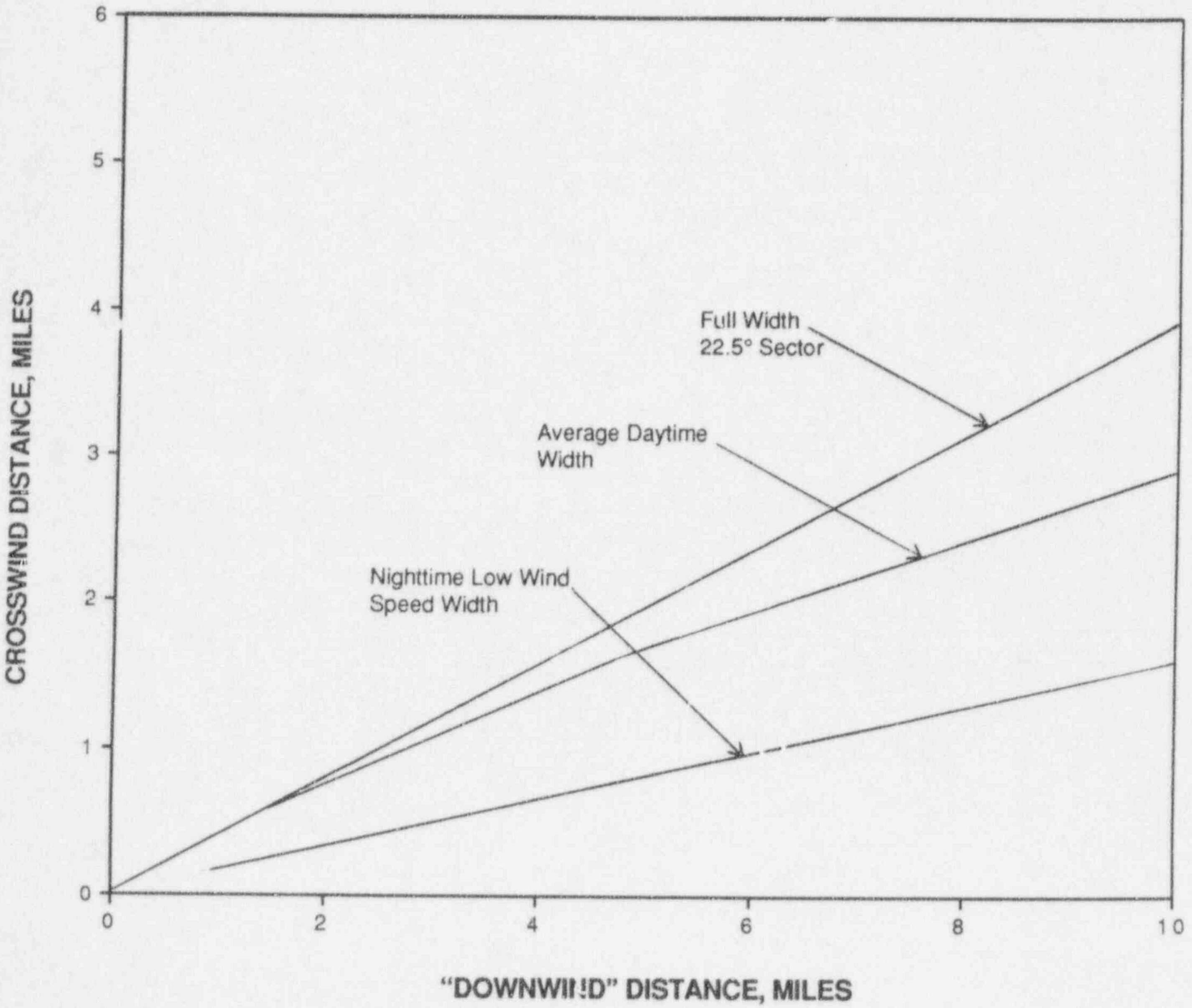
Inner Zone Radius vs Shielding Factor



Source: Personal Communication from Dr. H. Specter, New York Power Authority, April, 1988.

Figure 7

Theoretical Full Widths of Puffs at One Percent of Maximum Concentration vs Distance Along Track of Puff



Source: Reference 12

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