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Proceedings of the

Workshop on Meteorological Aspects of Emergency Response Plans for Nuclear Power Plants

Held at
Menlo Park, California
December 1-3, 1981

Compiled by S. SethuRaman, J. Tichler, A. Patrinos/ BNL
W. F. Dabbert, F. L. Ludwig, R. E. Ruff/ SRI

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FOREWORD

The Workshop on Meteorological Aspects of Emergency Response Plans for Nuclear Power Plants was held December 1-3, 1981, at SRI International in Menlo Park, California. The purpose of the workshop was to collect and integrate the comments of the user community on the Nuclear Regulatory Commission's (NRC's) atmospheric dispersion modeling requirements in support of nuclear power plant radiological emergency response plans. The user community was represented by utilities, consultants, and state and federal government agencies. The specific objective of the workshop was to develop detailed recommendations and guidance that utilities could use in complying with requirements set forth in NRC Report NUREG 0654 (Rev. 1), Appendix 2, entitled "Meteorological Criteria for Emergency Preparedness at Operating Nuclear Power Plants."

The workshop was organized into five short introductory technical sessions, followed by working sessions. The technical sessions provided an overview of the state of the art in health physics; release characteristics; transport, diffusion, and deposition; and operational aspects. Three working groups of approximately 15 members each met for two days to develop specific recommendations and guidance for implementation of the regulatory requirements. The three working groups addressed the themes of health physics and meteorology, release characteristics and meteorology, and dispersion and deposition.

This report summarizes the activities and results of both parts of the workshop. The main body of the report is organized in three chapters: an introduction; detailed recommendations of the three working groups; and a summary of the recommendations. The workshop program is given as Appendix C; extended abstracts of the introductory presentations are given in Appendix D. [Appendices A and B are provided for background and the convenience of the reader; they are reproductions of Appendices 1 and 2 from NRC Report NUREG 0654 (Rev. 1) and describe the technical aspects of the appropriate regulatory requirements.]

The recommendations should be considered in context. The working groups met for two days, during which time they identified the needs delineated in NUREG 0654; suggested and evaluated approaches; attempted to develop concise and practical recommendations; integrated their concerns with those of the other working groups; and documented their suggestions and recommendations. In many instances, recommended approaches to satisfying the requirements of NUREG 0654 were outlined, but time did not permit further refinement nor consideration of many of the practical aspects of implementation. Accordingly the recommendations contained in this report should be considered as the consensus opinion of the workshop participants expressed in schematic form; it is not an operational blueprint. It should also be recognized that while this report attempts to reflect the consensus viewpoint, there was not complete agreement by all participants on all issues. Prior to publication of this final report, a draft report was distributed to all participants; 20 sets of comments were received and were incorporated into this report. While the dissenting comments were few, no attempt has been made to summarize these minority views. Final responsibility for the representativeness of the contents rests with SRI International and Brookhaven National Laboratory.

CONTENTS

ACKNOWLEDGMENTS

The authors acknowledge with special thanks and appreciation the participation, suggestions, and hard work of those who helped with the organization and conduct of the meeting. In particular, we acknowledge the efforts of the three Working Group chairmen who focused and stimulated the work of the large and diverse working groups and helped draft the groups' recommendations: Mr. Ned Horton, General Electric Company, San Jose, California (Chairman, Working Group A--Health Physics and Meteorology); Mr. Robert Kornasiewicz, Nuclear Regulatory Commission, Silver Spring, Maryland (Chairman, Working Group B--Release Characteristics and Meteorology); and Dr. Bruce Hicks, National Oceanic and Atmospheric Administration, Oak Ridge, Tennessee (Chairman, Working Group C--Dispersion and Deposition).

The efforts of Mr. Robert Kornasiewicz (Contracting Officer's Technical Representative), Nuclear Regulatory Research Office, NRC, and Mr. Barry Zalcman, Office of Inspection and Enforcement, NRC, in organizing the workshop are gratefully acknowledged. Dr. Paul Michael, Director of Meteorology Department, Brookhaven National Laboratory, was instrumental in the organization of the workshop. The authors also extend their appreciation to Ms. Val Ramsay, SRI International, for her efforts and long hours in handling the substantial logistical and administrative load of the workshop. Finally, we thank those who attended and participated in the presentations and the deliberations of the working group; a list of the presentations is given in Appendix C. Complete lists of working group members are given in Section II.

I INTRODUCTION

A. Background

Following the 1979 accident at the Three Mile Island Nuclear Power Plant, the United States Nuclear Regulatory Commission (NRC) and the Federal Emergency Management Agency (FEMA) developed criteria for preparation and evaluation of radiological emergency response and preparedness plans in support of nuclear power plants; these criteria were contained in NRC Report NUREG 0654 (NRC/FEMA, 1980), first published in January 1980 and then published in revised form in October 1980. That report discusses planning and response activities and requirements, and prescribes various planning standards and evaluation criteria. It also defines four levels of emergency actions and provides associated response guidelines. Appendix A to this report contains the emergency action level guidelines presented in NUREG 0654. The four classes of emergency action levels are:

- Notification of an unusual event
- Alert
- Site area emergency
- General emergency.

These guidelines are included in this report for two reasons: first, they describe the various types of emergency classes that can occur, as well as the corresponding actions required of the utilities and state or local authorities. Second, the meteorological response capabilities specified in Appendix 2 to NUREG 0654 are in support of the classes of incidents described in Appendix A of this report. As such, the discussion of emergency action levels helps the reader better understand the context in which the meteorological response criteria would be used.

The meteorological criteria for emergency preparedness provided in NUREG 0654 are provided as well in this report (Appendix B). Three basic meteorological capabilities are required:

- Meteorological measurements.
- Near-real-time predictions of atmospheric effluent transport and diffusion.
- Remote interrogation of the atmospheric measurements and the dispersion predictions.

The meteorological measurements required (10 CFR Part 50, Appendix E) include equipment for determining the magnitude of and continuously assessing the effects of an atmospheric release of radioactive materials; both primary and backup systems are required (NRC, 1977a). Acceptance criteria for both the primary and backup meteorological measurements systems are contained in proposed Revision 1 to NRC Regulatory Guide 1.23 (NRC, 1980).

Federal regulations (10 CFR Part 50, Appendix E) require that there be the "means for determining the magnitude of and for continually assessing the impact of the release of radioactive materials." The system must make real-time (i.e. current), site-specific estimates of atmospheric effluent dispersion during and immediately following an accidental, airborne release of radioactive material. The purpose of these calculations is to aid in assessing the consequences of the release and in formulating and implementing emergency response activities. Two classes of "systems" or dispersion models are required. The Class A model (or procedure) must produce initial transport and diffusion estimates for the plume exposure emergency planning zone (EPZ), a zone of approximately 16-km radius from the plant; the licensee must be able to make Class A estimates within 15 minutes following designation of an incident. The Class A methodology must incorporate the following input and guidance:

- The methodology must use actual 15-minute meteorological data from the utility's measurement system or systems.
- Meteorological data must be representative of conditions throughout the plume exposure EPZ.
- The procedure must provide calculations of relative concentrations (χ/Q) and transport times.
- Atmospheric diffusion rates must be based on site-specific stability conditions that incorporate terrain conditions.
- Transport patterns must consider the effects of season, time-of-day, and terrain trajectories.
- Source effects (such as released height and mode, building wake effects, and so forth) must be factored into the Class A methodology.
- Model output must include plume position and dimensions, arrival time of peak relative concentration, and arrival time of relative concentrations at designated locations.

The second class of dispersion model, Class B, must necessarily be "a numerical* model which represents the actual spatial and temporal

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*Not to be interpreted in the literal sense as a numerical solution of a set of equations; rather "numerical" can include statistical, analytical, empirical, and strict numerical modeling approaches.

variations of plume distribution and can provide estimates of deposition and relative concentration of radioactivity within the plume exposure and ingestion EPZs for the duration of the release." The ingestion EPZ extends to a distance of 80 km from the plant.

The third meteorological criterion requires that there be provisions for communication among the nuclear power reactor control room, the on-site technical support center, and the near-site emergency operations facility as well as by the licensee with the NRC headquarters, the appropriate NRC Regional Office Operations Center, and the principal state and local emergency operations centers. Insofar as meteorological data communication is concerned, this requirement applies both to the basic meteorological measurements and the transport and diffusion calculations.

B. Focus of the Workshop

The workshop did not address the communication aspects of the meteorological criteria for emergency preparedness. Rather, the focus was on the requirements for obtaining necessary and representative meteorological measurements, and the requirements for producing useful and representative transport and dispersion calculations. Furthermore, the workshop attempted to develop recommendations in these two areas (i.e. measurements and calculations) with a conscious recognition of the needs of health physicists and other immediate users of this information. For this reason, the workshop was organized into three working groups with the following areas of concern:

- Health physics and meteorology
- Release characteristics and meteorology
- Transport, diffusion, and deposition.

As appropriate, measurement and calculation issues were addressed in each session. Overlap between the sessions was unavoidable, although it was minimized in plenary sessions conducted throughout the workshop.

II DETAILED RECOMMENDATIONS OF THE WORKING GROUPS

A. Working Group A--Health Physics and Meteorology

Chairman: Ned H. Horton, General Electric Company, San Jose, California

Reporters: Francis L. Ludwig, SRI International, Menlo Park, California; Ari Patrinos, Brookhaven National Laboratory, Upton, New York

Members: Eugene Bates, NRC/Inspection & Enforcement, Washington, D.C.; Stuart Bland, Nuclear Safety Associates, Bethesda, Maryland; John Cate, NOAA/Air Resources Field Office, Idaho Falls, Iowa; Raymond A. Crandall, Northeast Utilities, Hartford, Connecticut; Arthur E. Desrosiers, Pacific Northwest Laboratories, Richland, Washington; Richard Doty, TVA/Occupational Health & Safety, Muscle Shoals, Alabama; James L. McNees, Dept. of Public Health, State of Alabama, Montgomery; Walter Pasciak, NRC/Nuclear Reactor Regulation, Washington, D.C.; Malcolm Pendergast, Savannah River Laboratory, Aiken, South Carolina; Denning S. Powell, Northwest Utilities, Hartford, Connecticut; William Riethle, Three Mile Island/GPU Nuclear, Middletown, Pennsylvania; Douglas G. Smith, Environmental Research and Technology, Concord, Massachusetts; Thomas Sowdon, Boston Edison, Boston, Massachusetts; Irwin Spickler, NRC/Nuclear Reactor Regulation, Washington, D.C.; John Wilson, Stone & Webster Engineering Corp., Boston, Massachusetts; Keith Woodard, Pickard, Lowe & Garrick, Washington, D.C.

1. Introduction

After very broad discussions and solicitation of suggestions from every member of the group regarding topics that needed to be addressed, the group focused on two topics:

- Determining dose-related issues
- Directing field monitoring teams.

These two topics reflect the objectives that the group set for itself. It was generally agreed that the group's objective was to recommend techniques that could be used to translate airborne and deposited fission products into measures of dose consequence, which are necessary to the decision-making process and to the direction of field monitoring teams.

After consultation with the chairmen of the other Working Groups, the objectives were addressed under the assumption that the combined source and dispersion model outputs would provide estimates of the spatial and temporal distributions of activity that could be used for dose-related computations. The assumption was necessary to reduce the scope of the efforts to manageable proportions and to minimize overlap among the working groups.

The group also concluded relatively early in the discussions that the requirements for information, and the availability of information, were likely to be quite different during the first hour of an emergency than they would be at later times, and that personnel better able to interpret data would be available only after the Technical Support Center (TSC) had been established. Therefore, wherever appropriate, the recommendations were divided into two categories: those appropriate to the immediate time period (i.e. the first hour) and those for the intermediate (one hour to one day) time period. Later, it should be possible to draw upon the resources of other organizations such as the National Laboratories and outside contractors.

The resulting recommendations reflect two generally shared philosophies:

- The recommended procedures should be as simple as possible.
- The recommendations should not be overly specific, so that individual organizations can adapt them to their own special situations.

2. Recommendations

Dose Equivalent Calculations--Table 1 summarizes the recommendations of the Working Group relative to dose equivalent calculations. As noted before, it is expected that estimates of airborne activity (e.g. in an overhead plume) and ground deposition products would be provided to serve as input parameters for dose equivalent calculations. In making the recommendations, the group considered several different exposure pathways:

- The whole body dose to individuals
  - From the overhead plume
  - From the ground deposition.
- Thyroid inhalation dose
- Thyroid exposure from milk contamination

Table 1

SUMMARY OF THE RECOMMENDATIONS OF WORKING GROUP A (HEALTH PHYSICS AND METEOROLOGY) REFERRING TO DOSE EQUIVALENT CALCULATIONS

Exposure Pathway	Recommendations	Time Period*	
		Immediate	Intermediate
Whole body gamma dose from plume	Use finite cloud model for elevated releases	X	X
	For plume centerline at ground level, a semi-infinite cloud model is acceptable	X	X
	Neglect credit for shielding	X	X
	Estimated duration of the release:		
	Use observed value if available; if not use default value	X	
	Use observed or most reliable projected value		X
	Wind persistence:†		
	Use 95 percent persistence value (considering all sectors) based on past data from the specific site	X	
	Use current observations and forecasts		X
Whole body gamma dose from ground deposition	Not necessary to perform calculation	X	
	Capability for shielding can be included if desired; however, both shielded and nonshielded doses should be presented		X
	Use RG 1.109 dose conversion factors for nonshielded calculations		X
Inhalation dose	Consider dose to thyroid only	X	X
	Use NUREG 0172 dose conversion factors and associated breathing rate for the most critical age group	X	X
Beta skin dose	It is not necessary to perform calculations	X	X
Crop contamination/ liquid pathways	It is not necessary to perform calculations of crop contamination	X	X
	Base estimates on field measurements of crop contamination		X
Milk contamination	Calculate potential iodine contamination to a distance of 50 miles at 5-mile increments		X

*Immediate time period is 0-1 hours; intermediate time period is 1 hour to 1 day.

†This recommendation should not preclude due consideration of special conditions at specific sites.

- Ingestion from crop contamination or liquid pathways
- The beta skin dose.

Based on the requirements necessitating emergency action, the external gamma dose and the thyroid dose commitment were of most concern; therefore, the last two items in the above list were not considered to be sufficiently important to require special calculations.

As noted in Table 1, a finite cloud model is recommended for calculating centerline, versus sector averaged, concentrations from elevated releases during both the immediate and the intermediate time periods. For plume centerlines that are at ground level, a semi-infinite cloud model could be used; however, if a utility chose to use a finite dose model, that would also be acceptable.

The group suggested that credit for shielding not be included in the dose equivalent estimates being generated for emergency action purposes for either the intermediate or immediate time frames. For the types of analysis discussed, the effects of possible shielding (reducing the dose by 30 to 50 percent, depending upon the type of structure and the location within the structure) was not believed to warrant detailed treatment.

To calculate potential dose equivalents, it is necessary to estimate the duration of the release. If the release duration is known, or if it can be projected accurately during the immediate time period, then that knowledge or projection should be used. However, such information is frequently not available immediately, so it will often be necessary to use a default value for the release duration. Several default values should be developed so that a reasonable selection based on available plant parameters at the time of the accident can be made for use in the immediate dose calculations. For example, the selection of a default value could be based upon predetermined levels of activity monitored by instrumentation located in containment, or from radiation levels, temperature or pressure readings from other areas. From such readings, it should be possible to derive some expectations of whether or not the release would be relatively long-term or short-term. Better observations or projections of expected release duration are expected to become available during the intermediate period and should be used.

Another factor that affects the dose equivalent experienced at any given location is the persistence of the wind direction; the longer the wind remains in the same direction during a release, the greater will be the downwind dose in that direction. Reliable prognoses of wind direction during an expected period of release should be used when available. During the immediate time interval it is likely that such information will be unavailable, and the initial dose estimates must be based on some nominal value for the persistence of wind direction. The nominal persistence value should be derived from climatological data collected at the site. A frequency distribution of the length (in hours) of the periods when wind direction has remained within the same 22.5° sector (based on hourly observations) should be prepared. The 95th percentile value from that distribution should be used as an initial estimate for the number of hours that the wind will remain blowing from the current direction. The group recognized that this value will be conservative because it does not differentiate among different wind directions or weather conditions when selecting an interval for steady winds that is expected to be exceeded only 5 percent of the time. The Working Group felt that it was prudent to be conservative, but that some consideration should be given to special conditions at any given site. For example, if the prevailing winds are over a body of water (where the general population does not reside), then the 95 percent value chosen should be consistent with the frequency with which the wind fetch is over land.

After the immediate period has passed, calculated dose equivalents should be based upon observations of the conditions that have prevailed to that point and upon whatever projections are available.

As shown in Table 1, it is not necessary to calculate a whole body dose from ground deposition during the immediate time interval, but rather, it should be calculated later, during the intermediate time period. The calculation of ground deposition dose would be used to identify the location of potentially contaminated areas, rather than to provide a concrete measure of potential effects. A capability for estimating the effects of shielding could be included in the ground deposition-dose calculation, but if such a capability were included, it would be important to provide separate estimates of the shielded and unshielded doses, so that decisions could be made based on knowledge of the degree to which the local population was shielded. NRC Regulatory Guide 1.109 dose-conversion factors are recommended as appropriate to unshielded situations; appropriate adjustments would be necessary to treat shielded cases.

As regards inhalation dose, it is recommended that only the dose to the thyroid be considered for the time periods of interest; doses to other organs are not considered sufficiently important relative to the thyroid dose. In calculating the dose equivalent during both the immediate and intermediate time periods, it is recommended that dose conversion factors contained in NRC Report NUREG 0172 (1977c) be used in combination with breathing rates appropriate to an accident situation and the most critical age group (as appropriate to the site).

It is recommended that beta skin dose calculations <u>not</u> be made since no actions would be taken on the basis of the calculation. It is also recommended that estimates of doses from crop contamination or liquid pathways are unnecessary because the potential consequences can be derived from direct measurements.

The recommendation was made that milk contamination be estimated to a downwind distance of 50 miles (80 km)--state officials require this information--although it was also recognized that action toward condemnation of milk would rarely be made on the basis of these estimates; actual measurements of milk in the locations of concern are likely to be necessary. Nevertheless, the estimates of milk contamination that have been recommended for the intermediate time period would provide assistance to cognizant authorities in specifying what emergency action should be taken.

Response Time--The importance of providing dose estimates via the various exposure pathways and of having an indication of when the effects can be expected were both recognized. In the latter case, the group recommended at least two particular types of model output:

- The time that will be required for a plume to reach locations that have been identified by dose calculations as being of concern.
- The time required to reach Protective Action Guide (PAG) levels at:
  - The site boundary.
  - Two, five, and ten miles from the plant.
  - The off-site location(s) with maximum effects.

While the location of the maximum off-site dose is likely to be near the site boundary for a ground-level release, such factors as the exposure pathway, the effective release elevation, and the meteorological conditions existing at the time of the accident may result in a maximum off-site exposure location outside the site boundary.

Interpretation and Adjustments of Predicted Dose Based on Field Measurements--The Working Group engaged in considerable discussion relating to the degree to which field measurements should provide feedback to the calculated dose consequences. It concluded that such feedback should be attempted only if three criteria are satisfied:

- The off-site health physics measurements were obtained using appropriate procedures that had been established well in advance of the incident.
- Due consideration was given to all measurements (radiological and meteorological), the nature of the model and its input variables, and the associated uncertainties.
- Adjustments and interpretations relative to iodine and noble gases were made separately.

The first criterion is important because past experience (see, for example, the presentation in Appendix D by Eugene Bates) has shown that very misleading results can be obtained when improper procedures are followed and equipment becomes contaminated. It is strongly recommended that preestablished procedures be followed in performing field radiation monitoring. It is also recommended that multiple integrated measurements (e.g. over ten-minute periods) of gross gamma radiation be made, rather than instantaneous measurements. Finally, it is recommended that an industry standard be developed to provide guidance on field radiation measurement procedures and techniques in emergency situations.

The second criterion listed above concerns the interpretation of radiation measurements, and is intended to prevent the misuse of measurements that are not truly representative. If the data and the modeling results are all considered together, inconsistent observations or model outputs will be much more easily recognized. Furthermore, interpretation and adjustment should be attempted only with an understanding of the assumptions and simplifications that are inherent in the model being used.

The final criterion was included because measurements of iodine and of noble gas are generally related to different sources and different physical removal processes. It is not proper to make a correction for gases based on iodine measurements or vice versa. Whatever interpretations or adjustments are made for iodine or noble gases should be appropriate to the measurement being considered.

Information Required by Monitoring Teams--The recommendations regarding the information necessary to direct field monitoring teams apply after the immediate time period is past. The Working Group identified two items of particular importance in providing the necessary information:

- Output that provides clear information on current plume centerline location, which can be readily interpreted for the purpose of directing teams to areas of concern.
- Models with the capability to reassess plume location and projected doses periodically (e.g. every 15 minutes or less), and to incorporate measured meteorological and radiological data.

The above items reflect the group's belief that clear information, in terms of computer output or graphic displays, should be available somewhere within the control complex to provide definitive information regarding current plume location. The primary purpose of such output would be for directing health physics teams to important areas of concern. It would also be desirable if the model could evaluate the impacts of alternative contingencies. No matter how clearly presented the information from the models is, its reliability will depend on the capability of the model to make use of the most complete and most current information. The ability of the model to incorporate recent measurements from both on-site and off-site locations should be tempered, however, by the criteria discussed earlier.

B. Working Group B--Release Characteristics and Meteorology

Chairman: Robert Kornasiewicz, Nuclear Regulatory Commission, Silver Spring, Maryland

Reporters: Ronald E. Ruff, SRI International, Menlo Park, California; Joyce Tichler, Brookhaven National Laboratory, Upton, New York

Members: Ed Bradley, Sacramento Municipal Utility District, California; William B. Brenner, Commonwealth Edison, Chicago, Illinois; John Dodds, Bechtel Power Corporation, San Francisco, California; Robert Jaske, Federal Emergency Management Agency, Washington, D.C.; Stanley J. Krivo, Dames and Moore, Cranford, New Jersey; James Martin, NRC/Nuclear Reactor Regulation, Washington, D.C.; George W. Reynolds, TVA/Air Resources Program, Muscle Shoals, Alabama; Donald Shearer, TRC Environmental Consultants, Englewood, Colorado; Barry G. Wahlig, Applied Physical Technology, Smyrna, Georgia; Doug Wenzel, Exxon Nuclear, Idaho Falls, Idaho

1. Introduction

The objectives of the Working Group were to:

- Identify the types and characteristics of the releases that will be treated.
- Recommend generic methods that will help quantify the amount of the released material and its position with time, and their related uncertainties.
- Recommend measurements needed to implement methods defined in the above objectives.

In terms of plume position, this group assumed the responsibility for establishing the initial trajectory of the plume until the point that its position became a function of the mean transport winds. Hence, this responsibility included normal considerations of plume rise and building aerodynamic influences.

2. Discussion

The release of contaminants from nuclear plants cannot always be characterized by monitored pathways. Unmonitored pathway releases cover the spectrum from massive containment failures to small leakage paths at unknown locations. Even in monitored releases, the release rate may be known with uncertain precision. Where only gross measurements of noble gas, iodine, and particulate groups are available, the dose consequences are very dependent on the mix of nuclides within the groups. Furthermore, current stack monitoring equipment for iodine and particulates may actually have its response dominated by noble gases in the effluent stream.* Therefore, any initial dose projections may need to rely on assumed isotopic distributions and may be expected to be in error by factors of 10 or more. After 1 to 2 hours, estimates of the isotopic distributions may be known more accurately from grab sample analyses of effluent streams, although this may not always be the case.

Other properties of the release, such as plume rise, are of comparable importance to the quantification of the released compounds. Fortunately, for unmonitored releases the plume can be assumed to be close to the surface except in the case of massive containment failure.

Table 2 is a matrix that lists release properties and data requirements for plume rise and building wake calculations. It was acknowledged that several critical model input parameters would not be known at the time of an accident. Accordingly, it was recommended that all models have provision for manual data entries, at least as an option in the software. In particular, the release rate (Q) of the material would not be known for many types of accidents. However, the model would still be expected to provide information on the trajectory of the release. The Q-term will eventually be estimated and manually entered into the computer for later calculation of ambient concentrations and dosages. (The delay in obtaining Q is related to the inability of existing plant instrumentation to detect the released activity).

A further recommendation was that individuals responsible for estimating release rates early in accidents should use engineering judgment, especially with regard to the meaning of the response of iodine and particulate monitors. For example, if the effluent has passed intact through engineered safety features such as containment sprays or properly designed collectors (beds), then it may be reasonable to assume that iodines and particulates are minimally present in the streams. Plant procedures for making initial release-rate estimates should rely on existing design-basis accident analyses as modified by the age of the radioactive material and the presence and operability of engineered safety features. Furthermore, the procedures should include methods for making simplified estimates for major unanalyzed events, beginning from such factors as total core inventories of significant radionuclides.

It was also recognized that uncertainties exist in quantifying other characteristics of the release such as plume rise and building wake effects. In light of these, the group recommended that engineering judgement is needed to bound such parameters so that resulting model calculations reflect a range of likely values. The uncertainties of plume rise estimation for a massive containment failure are of

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*This interface is much less for silver zeolite cartridges, which sorb smaller amounts of noble gases than do the charcoal filters.

Table 2

DATA REQUIREMENTS FOR PROPERTIES OF SEVERAL RELEASE TYPES

Data Category	Massive Containment Failure	Design-Basis Accident			Unmonitored Release
		Stack	Ground	Fuel-Handling Accident[*]	
Release					
Compounds	NG, I, P[†]	NG, I, P (NG dominant; handle first)	NG, I, P (NG dominant; handle first)	NG, I, P	I, NG
Height	Elevated or ground, with or without steam	Elevated	Ground	Ground	Ground
Source terms	Unmonitored--Must back-calculate amounts of NG, I, and P released from field measurements made at a later time (several hours)	NG, monitored in real time; I, monitored but not real time; P, submicron sizes monitored but isotope analysis occurs several hours later[‡§]	Same as stack[‡§]	Same as stack[‡§]	Manual entry of Q values based on plant calculations
Anticipated duration	15 min to 2 days[§**]	Hours	Hours	1/2 hour	Hours
Plume rise	Default = 200 m; See Table 3[§]	See Reg. Guide 1.111, Briggs (1975)	Site-specific[††]	Ground	Ground
Source characteristics	Implicit	Stack diameter, height, exit velocity, and temperature	Vent area and height, exit velocity, and temperature	--	--
Building wake effects	Ignore	Ignore	Use default building wake calculations from Reg. Guide 1.145 or site specific information if available (not critical)	Same as ground	Same as ground
Required meteorological data[§§]	On-site data may not be available; use nearest representative site for estimates of winds, stability, and mixing height consistent with plume rise	$\Delta T/\Delta z$, wind speed/direction at plume height, ambient temperature	Wind speed/direction, ambient temperature, $\Delta T/\Delta z$	Wind speed and direction, $\Delta T/\Delta z$	Wind speed and direction, $\Delta T/\Delta z$

[*] Treatment depends on fuel types; See text.

[†] NG = noble gases, I = iodines, P = particulates.

[‡] Iodine can be back-estimated from field measurements, but it takes several hours.

[§] Model should provide for manual entry.

[**] Could last from less than 1 hour to several days. Can be estimated after it occurs. For advance warning, existing NRC guidance (NUREG 0654) should be used.

[††] Plant should use preestablished empirical values based on similarity of plant geometry to plant where test data exist (e.g. tracers, wind tunnel, Hosker reference.

[§§] May need to be estimated or calculated for plume height due to unavailability of direct measurements at plume level.

particular concern because of the variation of wind direction with height above ground. Accurate determination of the wind direction requires reasonable estimates of plume rise and a technique to extrapolate wind direction measurements to the height of concern. The final plume height (H_f) can be estimated as the sum of release height (h) and buoyant plume rise (Δh) using the methods developed by Briggs (1975); many other plume rise formulations have been developed and are also summarized in Briggs' work. For stable conditions, Briggs recommends the following formula to estimate the rise of a buoyant plume:

$$\Delta h = C_2\left(\frac{F}{Us}\right)^{1/3} \quad (1)$$

where F is a buoyancy parameter ($m^4 sec^{-3}$), U is the horizontal wind speed ($msec^{-1}$), and s is an ambient stability parameter (sec^{-2}) that is the square of the Brunt-Väissälä frequency. The stability parameter, s, is given as

$$s = \frac{g}{\theta_a}\frac{\partial\theta_a}{\partial_z} \quad (2)$$

where θ_a is the ambient potential temperature (degrees K), g is gravitational acceleration (9.8 $msec^{-2}$), and z is height (m). The buoyancy parameter, F, is a function of: the mean molecular weight of the efflux gas, m_o, relative to air (28.9); the absolute temperature, T_o, of the efflux gas relative to that of the ambient air, T_a; the sensible heat flux of the efflux gas, Q_H (cal sec^{-1});* and V_o, the initial volumetric flux (m^3):

$$F = \pi g(1 - m_o/28.9)\ (T_a/T_oV_o) + gQ_H/(\pi C_p\rho_aT_a) \quad (3)$$

where C_p is the specific heat capacity of air and ρ_a is the density of ambient air.

The first term in Eq. (3) can be deleted for the very warm emissions of combustion plumes, but may not always be insignificant for all accidental-release scenarios. Briggs cites values of the constant C_2 that range from 1.8 to 3.1, with most clustering in the range 2.3 to 2.9.

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*Q_H will not be known for most accidents; accordingly, worst-case scenarios will need to be assumed to provide an appropriate default value.

Final plume rise that is limited by ambient mechanical turbulence can be approximated (according to Briggs) by the relationship:

$$\Delta h = 1.3(F/Uu^{*2})\ (1 + h_s/\Delta h)^{2/3} \qquad (4)$$

where u* is the friction velocity (msec^{-1}) and h_s is the physical height of the stack above ground. Some examples of plume rise calculated with Briggs' (1975) recommendations are summarized in Table 3. Briggs' works (and those of others) consider many special considerations not discussed here, and should be referenced directly before applying any equation(s) to a particular site or release scenario.

Table 3

FINAL PLUME CENTERLINE HEIGHT FOR VARIOUS ENERGY RELEASE RATES AND METEOROLOGICAL CONDITIONS
(20-m Release Height Assumed)

Q_H, Energy Release Rate (cal/sec)	$\bar{u}$, Windspeed (m/sec)	Atmospheric Stability*	H_f, Final Plume Height (m)
1×10^6	2	A	110
	5	D	55
	2	F	80
5×10^6	2	A	250
	5	D	110
	2	F	120
1×10^7	2	A	370
	5	D	160
	2	F	140

*A = very unstable, D = neutral, F = moderately stable

C. Working Group C--Dispersion and Deposition

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1. Introduction

The Working Group considered the dispersion and deposition modeling requirements in the context of the Class A and Class B generic criteria provided in Appendix 2 to NRC Report NUREG 0654 (Rev. 1, October 1980); these criteria are summarized in Section I of this report and are reproduced in their entirety in Appendix B to this report. The modeling requirements can be fulfilled to varying degrees by one or more of four levels of model sophistication:

- Class A Models
  - Simple tabular or graphic "look-up" method
  - Computer-based, steady-state model (using real-time or default meteorological inputs, as available)

  - Computer-based, unsteady, near-mesoscale model (e.g. time and space-variable trajectories)

- Class B Model
  - Computer-based, unsteady, mesoscale model with deposition effects.

In general, the first three approaches fall within the Class A modeling category and the fourth, Class B. While reference is frequently made in discussion of Class A models to Gaussian-based methods, it is not the intent of the Working Group to endorse only this approach. Certainly, there exist a number of other approaches that can provide acceptable results, e.g. particle-in-cell, K-theory, finite element.

In the case of the Class A model, the Working Group recommends as first priority that the most comprehensive model required for a particular site be in operation at all times, so that it will automatically be available at the time of any incident. In the event this is not feasible, then the more simplified approaches can be implemented for use by on-site personnel in the time period (i.e. about one hour) immediately following an incident. As the technical support center is manned (i.e. at the start of the intermediate time period), the more comprehensive model should be activated if the simplistic method was used in the immediate phase. The discussion on the computer-based or more comprehensive models refers to the suitability of steady-state or so-called straight-line methods. The consensus of the group was that these methods are acceptable only if the applicant (i.e. utility) has demonstrated their applicability to a particular site. Insofar as curvilinear trajectories in both the plume exposure and ingestion EPZ are the result of either temporal or spatial variations in the wind field, it must be demonstrated that these variations are insignificant. Where this cannot be demonstrated, then the most sophisticated Class A method should be used.

2. Class A Models

General Comments--A Class A model is intended to provide the mechanism for an immediate, informed response in the event of an emergency. Output of such a model should be available, in easily understood form, at all times. This is important, because experience has shown that considerable delay can arise in starting-up computer codes and initializing them with real meteorological data. With the ready availability of automatic meteorological monitoring systems and microcomputing technology, it is now possible to have a Class A model running at all times, automatically updated with the most recent meteorological information. To guard against a power failure, an uninterruptible power supply (UPS) should be used. The equipment required for such automatic systems is commercially available at relatively low cost. Several additional favorable factors can be cited:

- On-site personnel would not need to take any action to initiate programming. Instead, the desired information for emergency purposes would always be displayed in simple form.
- In the event of a meteorological system failure, output based on the most recent meteorology would be on hand. In such cases, this output would provide the best basis for determining emergency response actions.
- Meteorological systems for driving such automated models are already in existence.

In view of the above considerations, it is recommended that site operators adopt the use of routine, automatic modeling systems for emergency response purposes. Existing guidelines allow any of a wide range of models to be used. However, because of the demands likely to be placed on control room personnel during the early stages of any emergency, model complexity should be minimized. (In this context, model complexity refers only to the complexity of the demands placed on personnel on site either for operating the model or interpreting the output; complexity does not refer here to the internal calculational procedure of the model.) The output should be provided in a manner that requires minimum meteorological knowledge for adequate interpretation. Producing and displaying model results using real-time data should be the first priority, with a display based on default assumptions as backup. As a minimum, the model should use real-time wind-direction data coupled with the assumption of the worst possible meteorological (i.e. "worst-case") conditions, determined as a function of time of day at the site in question.* Such a mode of minimal operation could use manual, hand-calculator, nomogram, or plume-overlay methods as a backup† in the event of a failure of the automatic systems.

A Class A model of the kind suggested here could use detailed meteorological information to allow careful examination of the circumstances of any particular emergency, as soon as time and sufficiently experienced personnel become available. This expanded capability usually will not be required prior to declaration of a site emergency and

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*Worst-case meteorological conditions should be determined as those combinations of wind speed, plume height, stability, inversion level(s), and so forth that result in maximum values of surface concentration; it should be recognized that there can be (and usually are) several combinations that lead to equivalently large surface concentrations and that these can occur at different source-receptor distances.

†The use of multiple backup methods offers many advantages at minimal cost or effort.

initiation of operations at the Technical Support Center; nevertheless, there is value in having this more detailed model output available at all times.

The Working Group recommended that the meteorological data required to drive a Class A model suitable for the purposes described above include the following parameters (listed in order of priority):

(1) Wind direction as a function of the effective elevation of the source.

(2) Wind speed as a function of source elevation.

(3) Wind direction standard deviation (depending on source height).

(4) The height of the mixed layer, or of the ground-based or elevated inversions that might limit vertical mixing (as detected by remote probing at the site or as estimated from other meteorological data).

(5) Appropriate meteorological measurements for determining the vertical plume dispersion rate for the source elevation and the meteorological circumstances in question; e.g. vertical temperature gradient.

Item 1, wind direction, is a singularly important input that should be considered at all times; it determines where exposure problems might be expected to occur. Item 2, wind speed, is a similarly simple and easily-considered quantity; it controls the rate of movement of material and the effective dilution of a continuing release.

Item 3, azimuthal standard deviation, controls the horizontal spreading (and hence dilution) of material in the plume. Evaluation of this quantity by automatic systems is now routine, and direct application of data of this kind should be expected.

Items 4 and 5 are strongly dependent on such meteorological factors as drainage flows along valleys, land/lake or land/sea circulations and cloud cover. Consideration of these factors requires a level of meteorological expertise that can be expected to be available at the TSC but that is not likely to be on hand at all times in a control room, or rapidly available there (i.e. to provide less than 15 minutes response).

In all cases, the Working Group recommended that special consideration be given to calms. In such circumstances, concentrations of material can build up in the immediate vicinity of release locations, and then migrate slowly and rather randomly once a little mean flow develops.

It recommended that special care be given to the identification of "default values" to be used at particular sites to eliminate the need for detailed meteorological interpretation while still providing adequate guidance for rational emergency response. Selection of appropriate values for such quantities as Items 4 and 5 above will be strongly site-specific, and special emphasis should be associated with the influence of local topographic features of a site and its surroundings. Default data should be selected on the basis of local climatological analyses, special field studies, or wind tunnel simulations.

While simple models like the straight-line Gaussian plume approach are probably adequate for use in most Class A applications, more sophisticated methods should be encouraged for some situations. In particular, the assumption of a straight-line trajectory cannot be easily defended whenever the surface is not spatially uniform or whenever conditions are changing with time. In such cases, some kind of trajectory model specially adjusted to the site in question would offer considerable advantages, while still being sufficiently simple for use in the Class A context considered here.

In the event of an anticipated emergency, expected to arise at some indeterminate time in the future, Class A models should be used to obtain information on when it is best to permit material to be released (if a choice is available), and on where potential exposures might be greatest. For such purposes, a forecasting mode of operation is required. The Working Group did not advocate the deployment of models capable of forecasting meteorological conditions; such services are available elsewhere. Useful forecasts can also be expected to be derived from site experience and local meteorological data provided such forecasting methods have been applied and evaluated prior to an emergency situation. However, in order to examine the potential consequences of future releases, the capability should exist for an interactive mode of model operation to enable adjustments to be made to the data on which its calculations are based.

Supplemental Data at Coastal and Complex Terrain Sites--On-site meteorological tower data, as required by NRC guidelines, will provide adequate data for Class A models in many circumstances, but terrain (and meteorological) complexities sometimes impose severe limitations. Phenomena that are likely to be important and that must be considered when making site-specific judgements about the adequacy of Class A models and meteorological data bases include:

- Nocturnal, low-level "jets," producing highly sheared wind maxima at levels of only 100 to 200 m above the surface.
- Land breezes over large water surfaces, causing high effluent concentrations over water during the night, which are then transported onshore at some time during the following day.
- Lake/sea breeze inflows, causing sharp reversals of wind direction at frontal boundaries, severely restricted mixing depths, and return flow layers in which plumes can become trapped while traveling in almost the opposite direction to low-level flows.

- River valley drainage flows which can channel effluents along topographically determined pathways, especially at night; or convection cells over wide rivers significantly warmer than the overlying air.
- Low-level windflow alterations imposed by complex terrain, which are often strongly influenced by atmospheric stability.

Numerous other phenomena can be identified. In most cases, these are not understood very well, although specific improvements can still be recommended in the structure of the models, the design of the meteorological monitoring system, or identifying periods in which the model should be used or may not be applicable.

Because of the special complexity of sites in coastal areas, with high probabilities of emitted materials entering recirculating flows regardless of the wind direction reported by on-site and nearby towers, the Working Group recommended that a program of site-specific scoping studies be undertaken. Scoping studies may consist of an in-depth analysis of existing meteorological data from the site and other nearby meteorological stations, or there may be a requirement for supplemental short-term meteorological or tracer studies. Further, a supplemental meteorological data system may be necessary for each coastal location, to provide additional wind field information. It is recommended that such supplemental systems be deployed unless it can be demonstrated that the flow field can adequately be described without additional wind measurements. The data obtained by such a supplemental meteorological monitoring system should be incorporated in Class A models in a manner that should be carefully evaluated on a site-by-site basis. Until such systems are in place, the group recommended that a coastal zone default procedure be adopted for routine Class A applications. This procedure should identify a circular zone of emergency response action, unless sufficient real-time supplemental, site-specific information is available to ensure the adequacy of alternative Class A predictions of more limited response requirement.

A similar default procedure should be adopted for other complex terrain sites. The area of such a default zone should be precalculated, based on climatological data and other special studies directed specifically at investigating such matters.

Techniques for Augmenting On-Site Data--Although simple dispersion models can provide acceptable information in many circumstances, such models are inappropriate for numerous combinations of topography and meteorology. Wind data from on-site primary and backup towers alone are insufficient to define plume transport and dispersion. In such situations (as discussed above), standard on-site data acquisition may need to be supplemented by using other sources, such as:

- Additional on-site and off-site in-situ sensors
- Remote sensing devices
- Regional weather data bases and forecasts.

In most circumstances, the phenomena that are likely to cause concern regarding the applicability of simple models in particular cases are known well enough that specific data-augmentation recommendations can be made. For example, sites near water bodies, near-shore and far-offshore water surface temperatures are valuable determinants of mesoscale air mass transformation, which can substantially influence plume behavior. Many utilities routinely monitor water temperature, and these data could well be applied here.

Acoustic sounding ("sodar") can significantly supplement tower measurements. Commercial sodar systems are available to provide automatic evaluations of the mixing height; two- and three-dimensional sodar systems can routinely measure u, v, and w components of the wind to heights often in excess of 500 m. Sodar systems can be applied to a large number of tasks, including detection of low-level jets, lake breeze circulations, mountain-valley circulations, outflows from convective cells, synoptic wind shifts, and elevated inversions.

For special purposes, and especially for Class B applications, other kinds of remote sensing offer advantages that should be considered carefully. In particular, modern meteorological radar offers the facility to detect precipitation at considerable distances. In rugged terrain, where the use of radar is often impractical, lightning detection networks provide an alternative method for detecting approaching rain systems and potential mesoscale wind perturbations. Satellite data might also be of use in some situations. Much of the information derived from such systems is included in the sets of meteorological data obtained from government sources [especially the National Weather Service (NWS), the Federal Aviation Administration (FAA), and various military services]. These more complicated considerations will be discussed later, when Class B applications are addressed.

Interaction Between Modeling and Monitoring Programs--Dispersion models are required not only for guiding immediate emergency response, but also for optimizing the design of measurements and monitoring activities. The Working Group recommended that field measurements and model outputs should frequently be cross-checked for consistency, to provide a basis for evaluating and updating model predictions and to determine if any measurements are suspect. Once a consistency is established between measurements and modeling, confidence in both is greatly enhanced.

Any single field observation is associated with a specific position in space and period of time. Interpretation of one or a few measurements should be made within this limitation. If measurements are made at a large number of locations (using a network of ground stations, or some mobile facility), it may be possible to obtain additional information including definition of plume boundaries, concentration profiles, and maximum concentrations.

By using normalized model calculations and airborne or ground-mobile measurements or air concentration that define the concentration patterns (especially maximum values), source strengths can be estimated. However, the group recommended caution in using this procedure, since order-of-magnitude errors can easily result.

Caution should also be exercised in using isolated measurements of dose equivalent or dose rate to evaluate model performance. The effects of many potential sources of error must be considered, including:

- Uncertainty in the composition and magnitude of the release.
- Small errors in the precise position, shape, and altitude of the plume at any particular instant.
- Normal plume meander and variability about properly determined mean values.
- Inadequacies of the input meteorological data (including instrument malfunctions).
- Errors in concentration measurement.

Model parameters should not be indiscriminately adjusted to make model estimates agree with isolated measurements. Similarly, a measurement should not be disregarded because it appears to be incompatible with model predictions. In terms of model/measurement interaction, a successful comparison between model output and field data provides significantly more information that does an unsuccessful comparison. Disagreement between model estimates and field measurements should be treated as an indication that further analysis or refinement is needed.

Accuracy and Limitation Considerations--Part of the selection and implementation of a modeling capability is an assessment of its accuracy, uncertainties, and limitations, each of which should be considered in the context of the intended use of the model. Some estimates of model uncertainties follow; these are presented in the context of χ/Q, rather than dose/Q, and discussion will be limited to one-hour averaged values. The simple Gaussian plume model is considered as a starting point.

When applied to a flat site during daytime with steady wind direction and speed, a simple Gaussian model will have uncertainties regarding the time of occurrence, concentrations, and location of ground-level exposure. The maximum (and near-maximum) normalized concentrations in the areas of impact can be modeled. Under these best of conditions, they can be calculated within about a factor of three. However, with the onset of near-calm winds, this error margin may approach a factor of ten.

For nighttime conditions, with all other considerations the same, specification of where the impact occurs becomes less precise. Model results for nonbuoyant, ground-level releases become more prone to overprediction than to underprediction. Model results are likely to depart from actual conditions in a range bounded by factors of three and ten.

Deviations from homogeneous flat terrain are likely in most circumstances, causing errors in the estimation of plume location and of ground-level exposure to the effluents. Estimates of χ/Q may differ from observations by factors ranging from 3 to 100. The locations and times of plume impacts will be highly uncertain because of these terrain-induced flow alterations.

Changing meteorological conditions (e.g. coastal wind circulations) are not addressed by the usual Gaussian plume formulations. Great uncertainties in the location of impact are then probable, and the use of more advanced models is recommended. Reliance on site instrumentation alone and simple, straight-line Gaussian modeling results in very large uncertainties in such circumstances. However, some of these uncertainties can be reduced, sometimes by an order of magnitude or more, by the application of readily available instrumentation and modeling techniques tailored to site-specific situations.

Potential Use of Tracer Injections--A potential mechanism for quantifying emission fluxes entails the controlled release of an inert, neutral-density gaseous tracer. In concept, a suitable release mechanism could be installed as an integral and operational part of the emergency response system with provision for release at several locations where radioactive leaks might occur. During an incident, the tracer gas could be released and subsequently monitored at fixed locations or from moving platforms (aerial or surface) using batch-type gas chromatography techniques or continuous electron-capture instruments. Coincident radiological and tracer concentration measurements would then yield straightforward estimates of the emission flux of the radioactive material (provided the tracer and the radioactive material are released at the same location). A second advantage of this technique is that it could be used to confirm transport patterns and diffusion rates in anticipation of possible radioactive releases (controlled or uncontrolled).

Set against the advantages of this technology are several potential disadvantages: the need to train personnel in release and monitoring practices and the addition of another level of complexity to the assessment and emergency response system. Potential use of the technique should be evaluated on a site by site basis; on the whole, this approach would be most attractive at sites where dispersion models are least reliable (and vice versa).

3. Class B Models

General Comments--It is anticipated that more complicated Class B models will be required for special purposes. As outlined in NUREG 0654, Appendix 2, Class B models require a level of sophistication considerably higher than for Class A (but may nevertheless be little more than an expanded form of a Class A model). Because the model is required to provide accurate guidance out to distances on the order of 80 km, there is need for a more extensive meteorological data set than is necessary to drive Class A calculations, and analysis will necessarily be more complicated. The level of expertise required is likely to become available only as TSC and EOF activities get underway. The data required to drive such a model should be obtained from a variety of outside sources as well as from local (including on-site) facilities.

The Working Group had difficulty in identifying a clear role for a Class B model in the context of immediate emergency response. Significant time delays are likely to be involved in starting up a Class B model, because much of the additional information required to drive it must be obtained from external sources, often imported as a consequence of the emergency itself. In practice, monitoring operations will probably provide more reliable information sufficiently quickly to address most of the practical requirements.

However, the group recognized the utility of having Class B modeling capabilities in the event of a continuing emergency situation, where predictions of surface concentrations, doses, and surface accumulations of material can be used to supplement monitoring information and to assist in the design of measurement programs.

For Class B applications, the movement of airborne material must be followed over distance and time scales for which assumptions of constant conditions are rarely satisfied. Consequently, the need exists to track air parcels, making use of a sufficient set of meteorological and supporting data. The composition of a "minimal yet sufficient data set" will vary from site to site. At shoreline locations, the strength of land/water circulations and the depth of internal boundary layers relative to the height of injection of material become critical matters that can be addressed experimentally--using, for example, acoustic remote probing systems ("sodars"; see above). Many nuclear power plants are located adjacent to rivers, which identify preferred routes for nocturnal drainage winds; a cloud of material released at low altitude into a near-calm atmosphere is likely to move downstream along the river at night, especially when river banks present significant obstacles to air movement. These two cases are presented as examples of situations in which a body of knowledge now exists concerning the movement of airborne material, but for which simple, straightline trajectory assumptions are singularly inappropriate. Instead, more rational procedures that recognize site peculiarities can be designed, and these need not be overly complicated.

In general, the models suitable for Class B application will be trajectory calculations with puff or plume diffusion components, segmented plume simulations, or similar techniques that utilize detailed three-dimensional knowledge of the wind field. The models should handle such factors as extended periods of calm. To provide information in the most useful way, models should be interactive and provide output in a timely manner. Adequate topographic and three-dimensional wind data must be included.

Because dry deposition is a matter of extreme complexity that is not yet fully understood, and because the resulting ground accumulation can be monitored, the group recommended that only simple parameterizations of this process should be incorporated in any Class B model. Rates of dry deposition are controlled linearly (to the first order) by concentrations near the surface. As a consequence, guidance regarding the spatial and temporal distribution of dry deposition can be obtained directly from concentration output. If desired, a simple deposition velocity formulation can be used to derive initial estimates. However, it should be recognized that deposition velocities may vary up to orders of magnitude depending on the physical and chemical properties of the release and the surface.

Similarly, precipitation scavenging should not be included in an overly complicated way. Fields of predicted concentration can be interfaced with wide-area precipitation patterns derived from radar observations, for example, to identify areas in which monitoring of wet deposition is likely to be necessary or beneficial for post-event analysis. Simple schemes for plume depletion commensurate with wet and dry deposition rates should be incorporated.

Sources of Supplemental Meteorological Data--In the preceding discussion of Class A models, instances were listed in which routine, onsite meteorological data would be inadequate for modeling plume dispersion out to distances of the order of 10 to 20 km. The larger spatial and temporal scales of Class B modeling amplify the difficulties associated with reliance on standard meteorological tower data. However, as mentioned previously, there is usually a large amount of additional meteorological data available from other sources. The most obvious of these other sources is the network of government (NWS, FAA, and military) surface and upper-air observations. However, surveys should also be conducted of alternative sources, such as fossil-fuel power plants, city and state air quality monitoring networks, and university and commercial monitoring systems (e.g. TV stations or chemical plants). Such data bases can often be interrogated via standard telephone dial-up systems.

NWS data and forecasts are readily available in error-checked, preformatted form through commercial services. These data can be tailored to the requirements of Class B models, and can include derived properties such as stability class information, estimated regional mixing depths, and geostrophic and gradient winds. This kind of information can either be used in detail in a rather complicated Class B model, or used to generate warning "flags" in simpler simulations.

Many complexities of the kind discussed above can be included in Class B models in virtually a "hands-off" automatic mode. However, interpretation of the outputs of such models will require a combination of meteorological expertise and detailed knowledge of local conditions. Most of the data resources will not be available to control room operators, although such data will be retrievable by TSC/EOF personnel.

III SUMMARY OF RECOMMENDATIONS

A. Summary of Working Group A Discussions

Working Group A focused on the problems of dose equivalent estimation and the direction of field monitoring teams, assuming that the output from source and dispersion models would provide estimates of spatial and temporal distributions of activity. The information availability and requirement during the first hour of an emergency (the immediate phase) will be very different from those at later (i.e. intermediate) times, so different recommendations were developed for the two time periods. The Working Group sought simple procedures that were not overly specific, so that individual organizations could adapt them to their special situations.

Four different exposure pathways were considered:

- Whole body dose from an overhead plume or ground-level deposition
- Thyroid dose from inhalation
- Liquid and crop contamination pathways
- The beta skin dose.

A finite dose model was recommended for elevated releases for both time periods; either the infinite or semi-infinite model would be acceptable for ground-level-releases. The magnitude of possible structural shielding effects and their uncertainty is such that the Working Group felt that the effort required to calculate credit for shielding was not warranted for either the intermediate or immediate time intervals.

Potential dose calculations require estimates of release duration. Of course, the most accurate projection should always be used, so conservative (but reasonable) values should be developed on the basis of information likely to be readily available during the immediate time period; e.g. from activity, temperature, pressure readings monitored by instruments located in containment or other areas. After the immediate time period, it is expected that better observations or projections will be available for use.

Another factor determining dose is the persistent wind direction; as with release duration the most reliable prognosis should be used. However, during the immediate time period dose estimates may have to be based on a nominal wind persistence. The Working Group recommended that such a value be derived from climatological statistics collected at the site, and that the 95 percentile value for periods when wind directions remain in the same 22.5° segment should be used to estimate the number of hours the wind will remain blowing in the current direction. This conservative estimate should be used only for the immediate time period and should be tempered by any special conditions known to prevail at the site. It is expected that better wind direction forecasts will become available after the immediate time period.

The Working Group recommended that whole body dose from ground deposition be calculated (assuming no shielding) for the intermediate time period, but would not be necessary in the immediate time period. The Working Group suggested the use of NRC Regulatory Guide 1.109, "Dose Conversion Factors," as appropriate for unshielded situations. If the effects of shielding were estimated, they should be displayed separately from the unshielded results.

The Working Group recommended that only inhalation dose to the thyroid (and not to other organs) be considered, using conversion factors named in NRC Report NUREG 0172 in combination with average breathing rates for the most critical age group. The Working Group did not feel that it was necessary to calculate beta skin doses, because no actions are likely to be implemented based on a skin dose.

The Working Group felt that although ground contamination doses can be calculated, doses from crop contamination or liquid pathways can best be derived from direct measurement, obviating some of the need for other estimates. Milk contamination estimates to downwind distances of 80 km may be required by state officials, although no action is likely to be taken toward condemnation of milk until confirmed by actual measurements. Nonetheless, estimates may be useful in identifying grazing herds whose milk may become contaminated so that they can be moved when this is practical.

In addition to dose estimates, it is also important to provide estimates of the time required for a plume to reach areas of concern and the time required to reach protective action guide (PAG) levels at the site boundary, the off-site location with maximum effects, and at a few other selected distances.

The Working Group recommended that calculated dose consequences be modified by the results of field measurements only if the off-site measurements were obtained using appropriate procedures (established well in advance of the accident) and due consideration had been given to all measurements, radiological and meteorological. Any such adjustments or interpretations should be made separately for iodine and noble gases.

Information will be required over the intermediate time interval to direct field monitoring teams with regard to plume location, size, and strength. Clear, easily interpreted graphic displays are recommended. They should be updated periodically to incorporate measured meteorological and radiological data.

B. Summary of Working Group B Discussions

Working Group B was given the responsibility for identifying and quantifying the characteristics of the releases that must be treated, including the type and amount of released material, location of release, and the initial trajectory.

The group's primary product was a table that provides guidance on how to characterize various types of releases, from massive containment failures and design-basis accidents to completely unmonitored releases. The release characteristics of interest were the source terms, height of release, anticipated duration, plume rise, and building wake effects. Real-time measurements and other necessary parameters for calculating plume rise were also defined. These measurements and parameters were considered to be an integral part of the dispersion model that is to be available at the plant.

It was recognized that significant uncertainties surround the quantification of many release characteristics, particularly the type and quantity of released material. Recommendations included improvements of real-time source monitors and other techniques that would expedite transfer of source data into the computer model.

C. Summary of Working Group C Discussions

Working Group C developed recommendations and guidance for simulation of dispersion and deposition effects in Class A and Class B models. Recommendations were also made for collection of suitable and representative measurements for input to both model classes. Recommendations of the Working Group follow, segregated according to model class. In the case of both Class A and B models, considerable emphasis should be placed on identification of the limits of applicability of the model(s) to specific sites and conditions. These limitations need to be determined for each site and model.

1. Class A Applications

The requirements of a Class A emergency preparedness modeling system are best met by the use of an automated model, using data obtained automatically and requiring minimal attention by on-site personnel. As a minimum, the model should employ real wind-direction data coupled with the assumption of "worst-case" meteorological conditions, determined as a function of time of day, for the particular site in question. Preferably, real-time site-specific measurements should be input to all model calculations. The use of straight-line trajectory models is unacceptable in coastal or complex terrain situations, or when conditions are changing with time, or when the wind is light or variable. Nomogram, plume overlay, hand-calculator, or manual-calculation methods should be available as backup, in case of a failure of the automatic system. Display of model output using real-time data should be routine, with a display based on default assumptions as a backup. The capability to use forecast meteorological data derived from other sources in an expanded form of the Class A model is desirable.

The order of priority of real-time meteorological measurements is:

- Wind direction
- Wind speed
- Wind direction standard deviation
- Mixed layer or inversion height
- Atmospheric stability.

The first three items should be available as primary functions of height.

In complex terrain, and especially at coastal sites, a program of site-specific dispersion and transport studies should be undertaken (including theoretical studies, modeling investigations, or on-site dispersion experiments), and meteorological measurement programs should be expanded according to the results. Such supplemental meteorological data should be used in the Class A model that is routinely operational at the site. Until such improved systems are operational at complex sites, a circular zone of emergency response action should be used. This zone should be defined on the basis of site-specific meteorological and topographical information.

Whenever possible, model output should be checked against field observations to generate confidence in both the modeling and the observation programs. However, considerable caution should be exercised in using models and field concentration data to estimate source strengths (i.e. emission rates).

Finally, there is a benefit in having a more detailed and more advanced form of the Class A model available, especially for supporting operations of the Technical Support Center. Interpretation of the output of such a more sophisticated model is likely to require more expert knowledge than is available in normal control room operations.

2. Class B Applications

A more sophisticated model is required if Class B applications are to be addressed. Input data to such a model should be supplemented by information from external (e.g. NWS) sources. Class B models will generally be trajectory calculations with puff or plume diffusion components, segmented plume models, or similar simulations that utilize detailed knowledge of wind fields. Such models may be expanded forms of Class A models. Class B models should be capable of using forecast data, for use in a predictive mode.

Dry and wet deposition should be included in Class B models, but the level of complexity should not be great. The use of a simple deposition-velocity formulation is all that is warranted currently, although such formulations can be subject to large uncertainties. Estimates of the distribution of wet deposition can be obtained by interfacing precipitation patterns (e.g. as determined by radar) with predicted air concentrations.

REFERENCES

Briggs, 1975: "Plume Rise Predictions," in *Lectures on Air Pollution and Environmental Impact Analysis*, D.A. Haugen, ed., American Meteorological Society, pp. 59-111.

Dickerson, M., 1982: Personal communication to W. Dabberdt, Lawrence Livermore Laboratory, Livermore, California 94550.

NRC, 1977a: "Calculation of Annual Doses to Man From Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR, Part 50, Appendix I," Regulatory Guide 1.109. U.S. Nuclear Regulatory Commission, Washington, D.C. (October).

NRC, 1977b: "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," Regulatory Guide 1.111, Revision 1, U.S. Nuclear Regulatory Commission, Washington, D.C. (July).

NRC, 1977c: "Age-Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake," NUREG 0172, prepared for U.S. Nuclear Regulatory Commission, Office of Standards Development, by Pacific Northwest Laboratories, Richland, Washington, NTIS PB-275-348.

NRC, 1979: "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," Regulatory Guide 1.145, U.S. Nuclear Regulatory Commission, Office of Standards Development, Washington, D.C. (August).

NRC, 1980: "Meteorological Programs in Support of Nuclear Power Plants," Proposed Revision* to Regulatory Guide 1.23, U.S. Nuclear Regulatory Commission, Washington, D.C. (November).

NRC/FEMA, 1980: "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, D.C. (October).

Appendix A

NUREG 0654 (Rev. 1), Appendix 1: "EMERGENCY ACTION LEVEL GUIDELINES FOR NUCLEAR POWER PLANTS"*

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*Source: NRC/FEMA Report NUREG 0654, Rev. 1, Appendix 1 (October 1980)

BASIS FOR EMERGENCY ACTION LEVELS FOR NUCLEAR POWER FACILITIES

Four classes of Emergency Action Levels are established which replace the classes in Regulatory Guide 1.101, each with associated examples of initiating conditions. The classes are:

Notification of Unusual Event

Alert

Site Area Emergency

General Emergency

The rationale for the notification and alert classes is to provide early and prompt notification of minor events which could lead to more serious consequences given operator error or equipment failure or which might be indicative of more serious conditions which are not yet fully realized. A gradation is provided to assure fuller response preparations for more serious indicators. The site area emergency class reflects conditions where some significant releases are likely or are occurring but where a core melt situation is not indicated based on current information. In this situation full mobilization of emergency personnel in the near site environs is indicated as well as dispatch of monitoring teams and associated communications. The general emergency class involves actual or imminent substantial core degradation or melting with the potential for loss of containment. The immediate action for this class is sheltering (staying inside) rather than evacuation until an assessment can be made that (1) an evacuation is indicated and (2) an evacuation, if indicated, can be completed prior to significant release and transport of radioactive material to the affected areas.

The example initiating conditions listed after the immediate actions for each class are to form the basis for establishment by each licensee of the specific plant instrumentation readings (as applicable) which, if exceeded, will initiate the emergency class.

Potential NRC actions during various emergency classes are given in NUREG-0728, Report to Congress: NRC Incident Response Plan. The NRC response to any notification from a licensee will be related to, but not limited by, the licensee estimate of severity; NRC will consider such other factors as the degree of uncertainty and the lead times required to position NRC response personnel should something more serious develop.

Prompt notification of offsite authorities is intended to indicate within about 15 minutes for the unusual event class and sooner (consistent with the need for other emergency actions) for other classes. The time is measured from the time at which operators recognize that events have occurred which make declaration of an emergency class appropriate.

Class	Licensee Actions	State and/or Local Offsite Authority Actions
NOTIFICATION OF UNUSUAL EVENT Class Description Unusual events are in process or have occurred which indicate a potential degradation of the level of safety of the plant. No releases of radioactive material requiring offsite response or monitoring are expected unless further degradation of safety systems occurs. Purpose Purpose of offsite notification is to (1) assure that the first step in any response later found to be necessary has been carried out, (2) bring the operating staff to a state of readiness, and (3) provide systematic handling of unusual events information and decisionmaking.	1. Promptly inform State and/or local offsite authorities of nature of unusual condition as soon as discovered 2. Augment on-shift resources as needed 3. Assess and respond 4. Escalate to a more severe class, if appropriate or 5. Close out with verbal summary to offsite authorities; followed by written summary within 24 hours	1. Provide fire or security assistance if requested 2. Escalate to a more severe class, if appropriate 3. Stand by until verbal closeout

EXAMPLE INITIATING CONDITIONS: NOTIFICATION OF UNUSUAL EVENT

1. Emergency Core Cooling System (ECCS) initiated and discharge to vessel
2. Radiological effluent technical specification limits exceeded
3. Fuel damage indication. Examples:
    a. High offgas at BWR air ejector monitor (greater than 500,000 uci/sec; corresponding to 16 isotopes decayed to 30 minutes; <u>or</u> an increase of 100,000 uci/sec within a 30 minute time period)
    b. High coolant activity sample (e.g., exceeding coolant technical specifications for iodine spike)
    c. Failed fuel monitor (PWR) indicates increase greater than 0.1% equivalent fuel failures within 30 minutes
4. Abnormal coolant temperature and/or pressure or abnormal fuel temperatures outside of technical specification limits
5. Exceeding either primary/secondary leak rate technical specification or primary system leak rate technical specification
6. Failure of a safety or relief valve in a safety related system to close following reduction of applicable pressure
7. Loss of offsite power or loss of onsite AC power capability
8. Loss of containment integrity requiring shutdown by technical specifications
9. Loss of engineered safety feature or fire protection system function requiring shutdown by technical specifications (e.g., because of malfunction, personnel error or procedural inadequacy)
10. Fire within the plant lasting more than 10 minutes
11. Indications or alarms on process or effluent parameters not functional in control room to an extent requiring plant shutdown or other significant loss of assessment or communication capability (e.g., plant computer, Safety Parameter Display System, all meteorological instrumentation)
12. Security threat or attempted entry or attempted sabotage
13. Natural phenomenon being experienced or projected beyond usual levels
    a. Any earthquake felt in-plant or detected on station seismic instrumentation
    b. 50 year floor or low water, tsunami, hurricane surge, seiche
    c. Any tornado on site
    d. Any hurricane

14. Other hazards being experienced or projected

    a. Aircraft crash on-site or unusual aircraft activity over facility

    b. Train derailment on-site

    c. Near or onsite explosion

    d. Near or onsite toxic or flammable gas release

    e. Turbine rotating component failure causing rapid plant shutdown

15. Other plant conditions exist that warrant increased awareness on the part of a plant operating staff or State and/or local offsite authorities or require plant shutdown under technical specification requirements or involve other than normal controlled shutdown (e.g., cooldown rate exceeding technical specification limits, pipe cracking found during operation)

16. Transportation of contaminated injured individual from site to offsite hospital

17. Rapid depressurization of PWR secondary side.

Class	Licensee Actions	State and/or Local Offsite Authority Actions
ALERT **Class Description** Events are in process or have occurred which involve an actual or potential substantial degradation of the level of safety of the plant. Any releases expected to be limited to small fractions of the EPA Protective Action Guideline exposure levels. **Purpose** Purpose of offsite alert is to (1) assure that emergency personnel are readily available to respond if situation becomes more serious or to perform confirmatory radiation monitoring if required, and (2) provide offsite authorities current status information.	1. Promptly inform State and/or local authorities of alert status and reason for alert as soon as discovered 2. Augment resources and activate on-site Technical Support Center and on-site operational support center. Bring Emergency Operations Facility (EOF) and other key emergency personnel to standby status 3. Assess and respond 4. Dispatch on-site monitoring teams and associated communications 5. Provide periodic plant status updates to offsite authorities (at least every 15 minutes) 6. Provide periodic meteorological assessments to offsite authorities and, if any releases are occurring, dose estimates for actual releases 7. Escalate to a more severe class, if appropriate 8. Close out or recommend reduction in emergency class by verbal summary to offsite authorities followed by written summary within 8 hours of closeout or class reduction	1. Provide fire or security assistance if requested 2. Augment resources and bring primary response centers and EBS to standby status 3. Alert to standby status key emergency personnel including monitoring teams and associated communications 4. Provide confirmatory offsite radiation monitoring and ingestion pathway dose projections if actual releases substantially exceed technical specification limits 5. Escalate to a more severe class, if appropriate 6. Maintain alert status until verbal closeout or reduction of emergency class

EXAMPLE INITIATING CONDITIONS: ALERT

1. Severe loss of fuel cladding

   a. High offgas at BWR air ejector monitor (greater than 5 ci/sec; corresponding to 16 isotopes decayed 30 minutes)

   b. Very high coolant activity sample (e.g., 300 uci/cc equivalent of I-131)

   c. Failed fuel monitor (PWR) indicates increase greater than 1% fuel failures within 30 minutes or 5% total fuel failures.

2. Rapid gross failure of one steam generator tube with loss of offsite power

3. Rapid failure of steam generator tubes (e.g., several hundred gpm primary to secondary leak rate)

4. Steam line break with significant (e.g., greater than 10 gpm) primary to secondary leak rate (PWR) or MSIV malfunction causing leakage (BWR)

5. Primary coolant leak rate greater than 50 gpm

6. Radiation levels or airborne contamination which indicate a severe degradation in the control of radioactive materials (e.g., increase of factor of 1000 in direct radiation readings within facility)

7. Loss of offsite power and loss of all onsite AC power (see Site Area Emergency for extended loss)

8. Loss of all onsite DC power (See Site Area Emergency for extended loss)

9. Coolant pump seizure leading to fuel failure

10. Complete loss of any function needed for plant cold shutdown

11. Failure of the reactor protection system to initiate and complete a scram which brings the reactor subcritical

12. Fuel damage accident with release of radioactivity to containment or fuel handling building

13. Fire potentially affecting safety systems

14. Most or all alarms (annunciators) lost

15. Radiological effluents greater than 10 times technical specification instantaneous limits (an instantaneous rate which, if continued over 2 hours, would result in about 1 mr at the site boundary under average meteorological conditions)

16. Ongoing security compromise

17. Severe natural phenomena being experienced or projected

    a. Earthquake greater than OBE levels

    b. Flood, low water, tsunami, hurricane surge, seiche near design levels

    c. Any tornado striking facility

    d. Hurricane winds near design basis level

18. Other hazards being experienced or projected

    a. Aircraft crash on facility

    b. Missile impacts from whatever source on facility

    c. Known explosion damage to facility affecting plant operation

    d. Entry into facility environs of uncontrolled toxic or flammable gases

    e. Turbine failure causing casing penetration

19. Other plant conditions exist that warrant precautionary activation of technical support center and placing near-site Emergency Operations Facility and other key emergency personnel on standby

20. Evacuation of control room anticipated or required with control of shutdown systems established from local stations

Class	Licensee Actions	State and/or Local Offsite Authority Actions
SITE AREA EMERGENCY Class Description Events are in process or have occurred which involve actual or likely major failures of plant functions needed for protection of the public. Any releases not expected to exceed EPA Protective Action Guideline exposure levels except near site boundary. Purpose Purpose of the site area emergency declaration is to (1) assure that response centers are manned, (2) assure that monitoring teams are dispatched, (3) assure that personnel required for evacuation of near-site areas are at duty stations if situation becomes more serious, (4) provide consultation with offsite authorities, and (5) provide updates for the public through offsite authorities.	1. Promptly inform State and/or local offsite authorities of site area emergency status and reason for emergency as soon as discovered 2. Augment resources by activating on-site Technical Support Center, on-site operational support center and near-site Emergency Operations Facility (EOF) 3. Assess and respond 4. Dispatch on-site and offsite monitoring teams and associated communications 5. Dedicate an individual for plant status updates to offsite authorities and periodic pressure briefings (perhaps joint with offsite authorities) 6. Make senior technical and management staff onsite available for consultation with NRC and State on a periodic basis 7. Provide meteorological and dose estimates to offsite authorities for actual releases via a dedicated individual or automated data transmission 8. Provide release and dose projections based on available plant condition information and foreseeable contingencies 9. Escalate to general emergency class, if appropriate or 10. Close out or recommend reduction in emergency class by briefing of offsite authorities at EOF and by phone followed by written summary within 8 hours of closeout or class reduction	1. Provide any assistance requested 2. If sheltering near the site is desirable, activate public notification system within at least two miles of the plant 3. Provide public within at least about 10 miles periodic updates on emergency status 4. Augment resources by activating primary response centers 5. Dispatch key emergency personnel including monitoring teams and associated communications 6. Alert to standby status other emergency personnel (e.g., those needed for evacuation) and dispatch personnel to near-site duty stations 7. Provide offsite monitoring results to licensee, DOE and others and jointly assess them 8. Continuously assess information from licensee and offsite monitoring with regard to changes to protective actions already initiated for public and mobilizing evacuation resources 9. Recommend placing milk animals within 2 miles on stored feed and assess need to extend distance 10. Provide press briefings, perhaps with licensee 11. Escalate to general emergency class, if appropriate 12. Maintain site area emergency status until closeout or reduction of emergency class

EXAMPLE INITIATING CONDITIONS: SITE AREA EMERGENCY

1. Known loss of coolant accident greater than makeup pump capacity
2. Degraded core with possible loss of coolable geometry (indicators should include instrumentation to detect inadequate core cooling, coolant activity and/or containment radioactivity levels)
3. Rapid failure of steam generator tubes (several hundred gpm leakage) with loss of offsite power
4. BWR steam line break outside containment without isolation
5. PWR steam line break with greater than 50 gpm primary to secondary leakage and indication of fuel damage
6. Loss of offsite power <u>and</u> loss of onsite AC power for more than 15 minutes
7. Loss of all vital onsite DC power for more than 15 minutes
8. Complete loss of any function needed for plant hot shutdown
9. Transient requiring operation of shutdown systems with failure to scram (continued power generation but no core damage immediately evident)
10. Major damage to spent fuel in containment or fuel handling building (e.g., large object damages fuel or water loss below fuel level)
11. Fire compromising the functions of safety systems
12. Most or all alarms (annunciators) lost and plant transient initiated or in progress
13. a. Effluent monitors detect levels corresponding to greater than 50 mr/hr for 1/2 hour <u>or</u> greater than 500 mr/hr W.B. for two minutes (or five times these levels to the thyroid) at the site boundary <u>for adverse meteorology</u>

    b. These dose rates are projected based on other plant parameters (e.g., radiation level in containment with leak rate appropriate for existing containment pressure) or are measured in the environs

    c. EPA Protective Action Guidelines are projected to be exceeded outside the site boundary
14. Imminent loss of physical control of the plant
15. Severe natural phenomena being experienced or projected with plant not in cold shutdown

    a. Earthquake greater than SSE levels

   b. Flood, low water, tsunami, hurricane surge, seiche greater than design levels or failure of protection of vital equipment at lower levels

   c. Sustained winds or tornadoes in excess of design levels

16. Other hazards being experienced or projected with plant not in cold shutdown

   a. Aircraft crash affecting vital structures by impact or fire

   b. Severe damage to safe shutdown equipment from missiles or explosion

   c. Entry of uncontrolled flammable gases into vital areas. Entry of uncontrolled toxic gases into vital areas where lack of access to the area constitutes a safety problem

17. Other plant conditions exist that warrant activation of emergency centers and monitoring teams or a precautionary notification to the public near the site

18. Evacuation of control room and control of shutdown systems not established from local stations in 15 minutes

Class	Licensee Actions	State and/or Local Offsite Authority Actions
GENERAL EMERGENCY Class Description Events are in process or have occurred which involve actual or imminent substantial core degradation or melting with potential for loss of containment integrity. Releases can be reasonably expected to exceed EPA Protective Action Guideline exposure levels offsite for more than the immediate site area. Purpose Purpose of the general emergency declaration is to (1) initiate predetermined protective actions for the public, (2) provide continuous assessment of information from licensee and offsite organization measurements, (3) initiate additional measures as indicated by actual or potential releases, (4) provide consultation with offsite authorities and (5) provide updates for the public through offsite authorities.	1. Promptly inform State and local offsite authorities of general emergency status and reason for emergency as soon as discovered (Parallel notification of State/local) 2. Augment resources by activating on-site Technical Support Center, on-site operational support center and near-site Emergency Operations Facility (EOF) 3. Assess and respond 4. Dispatch on-site and offsite monitoring teams and associated communications 5. Dedicate an individual for plant status updates to offsite authorities and periodic press briefings (perhaps joint with offsite authorities) 6. Make senior technical and management staff onsite available for consultation with NRC and State on a periodic basis 7. Provide meteorological and dose estimates to offsite authorities for actual releases via a dedicated individual or automated data transmission 8. Provide release and dose projections based on available plant condition information and foreseeable contingencies 9. Close out or recommend reduction of emergency class by briefing of offsite authorities at EOF and by phone followed by written summary within 8 hours of closeout or class reduction	1. Provide any assistance requested 2. Activate immediate public notification of emergency status and provide public periodic updates 3. Recommend sheltering for 2 mile radius and 5 miles downwind and assess need to extend distances. Consider advisability of evacuation (projected time available vs. estimated evacuation times) 4. Augment resources by activating primary response centers 5. Dispatch key emergency personnel including monitoring teams and associated communications 6. Dispatch other emergency personnel to duty stations within 5 mile radius and alert all others to standby status 7. Provide offsite monitoring results to licensee, DOE and others and jointly assess them 8. Continuously assess information from licensee and offsite monitoring with regard to changes to protective actions already initiated for public and mobilizing evacuation resources 9. Recommend placing milk animals within 10 miles on stored feed and assess need to extend distance 10. Provide press briefings, perhaps with licensee 11. Maintain general emergency status until closeout or reduction of emergency class

EXAMPLE INITIATING CONDITIONS: GENERAL EMERGENCY

1. a. Effluent monitors detect levels corresponding to 1 rem/hr W.B. or 5 rem/hr thyroid at the site boundary under actual meteorological conditions

   b. These dose rates are projected based on other plant parameters (e.g., radiation levels in containment with leak rate appropriate for existing containment pressure with some confirmation from effluent monitors) or are measured in the environs

   Note: Consider evacuation only within about 2 miles of the site boundary unless these site boundary levels are exceeded by a factor of 10 or projected to continue for 10 hours or EPA Protective Action Guideline exposure levels are predicted to be exceeded at longer distances

2. Loss of 2 of 3 fission product barriers with a potential loss of 3rd barrier, (e.g., loss of primary coolant boundary, clad failure, and high potential for loss of containment)

3. Loss of physical control of the facility

   Note: Consider 2 mile precautionary evacuation

4. Other plant conditions exist, from whatever source, that make release of large amounts of radioactivity in a short time period possible, e.g., any core melt situation. See the specific PWR and BWR sequences below.

   Notes: a. For core melt sequences where significant releases from containment are not yet taking place and large amounts of fission products are not yet in the containment atmosphere, consider 2 mile precautionary evacuation. Consider 5 mile downwind evacuation (45° to 90° sector) if large amounts of fission products (greater than gap activity) are in the containment atmosphere. Recommend sheltering in other parts of the plume exposure Emergency Planning Zone under this circumstance.

   b. For core melt sequences where significant releases from containment are not yet taking place and containment failure leading to a direct atmospheric release is likely in the sequence but not imminent and large amounts of fission products in addition to noble gases are in the containment atmosphere, consider precautionary evacuation to 5 miles and 10 mile downwind evacuation (45° to 90° sector).

   c. For core melt sequences where large amounts of fission products other than noble gases are in the containment atmosphere and containment failure is judged imminent, recommend shelter for those areas where evacuation cannot be completed before transport of activity to that location.

d. As release information becomes available adjust these actions in accordance with dose projections, time available to evacuate and estimated evacuation times given current conditions.

5. Example PWR Sequences

   a. Small and large LOCA's with failure of ECCS to perform leading to severe core degradation or melt in from minutes to hours. Ultimate failure of containment likely for melt sequences. (Several hours likely to be available to complete protective actions unless containment is not isolated)

   b. Transient initiated by loss of feedwater and condensate systems (principal heat removal system) followed by failure of emergency feedwater system for extended period. Core melting possible in several hours. Ultimate failure of containment likely if core melts.

   c. Transient requiring operation of shutdown systems with failure to scram which results in core damage or additional failure of core cooling and makeup systems (which could lead to core melt)

   d. Failure of offsite and onsite power along with total loss of emergency feedwater makeup capability for several hours. Would lead to eventual core melt and likely failure of containment.

   e. Small LOCA and initially successful ECCS. Subsequent failure of containment heat removal systems over several hours could lead to core melt and likely failure of containment.

   NOTE: Most likely containment failure mode is melt-through with release of gases only for dry containment; quicker and larger releases likely for ice condenser containment for melt sequences. Quicker releases expected for failure of containment isolation system for any PWR.

6. Example BWR Sequences

   a. Transient (e.g., loss of offsite power) plus failure of requisite core shut down systems (e.g., scram). Could lead to core melt in several hours with containment failure likely. More severe consequences if pumps trip does not function.

   b. Small or large LOCA's with failure of ECCS to perform leading to core melt degradation or melt in minutes to hours. Loss of containment integrity may be imminent.

   c. Small or large LOCA occurs and containment performance is unsuccessful affecting longer term success of the ECCS. Could lead to core degradation or melt in several hours without containment boundary.

d. Shutdown occurs but requisite decay heat removal systems (e.g., RHR) or non-safety systems heat removal means are rendered unavailable. Core degradation or melt could occur in about ten hours with subsequent containment failure.

7. Any major internal or external events (e.g., fires, earthquakes, substantially beyond design basis) which could cause massive common damage to plant systems resulting in any of the above.

Appendix B

NUREG 0654 (Rev. 1), Appendix 2: "METEOROLOGICAL CRITERIA FOR EMERGENCY PREPAREDNESS AT OPERATING NUCLEAR POWER PLANTS*"

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*Source: NRC/FEMA Report NUREG 0654, Rev. 1, Appendix 2 (October 1980)

APPENDIX 2

METEOROLOGICAL CRITERIA FOR EMERGENCY PREPAREDNESS AT OPERATING NUCLEAR POWER PLANTS

Introduction

10 CFR Part 50.47 requires that the Emergency Plan shall provide "(A)dequate methods, systems, and equipment for assessing and monitoring actual or potential offsite consequences of a radiological emergency condition ..."

The basic functions needed to comply with the meteorological aspects of these requirements are:

1. A capability for making meteorological measurements.

2. A capability for making near real-time predictions of the atmospheric effluent transport and diffusion.

3. A capability for remote interrogation of the atmospheric measurements and predictions by appropriate organizations.

A staged schedule is provided in Annex 1 to this appendix for implementation of the meteorological elements addressing emergency preparedness requirements.

Meteorological Measurements

The emergency facilities and equipment as stated in Appendix E to 10 CFR Part 50 shall include "(E)quipment for determining the magnitude of and for continuously assessing the impact of the release of radioactive materials to the environment." To address this requirement, in part, the nuclear power plant operator shall have meteorological measurements from primary and backup systems.

Each site with an operating nuclear power plant shall have a primary meteorological measurements system. The primary system shall produce current and record historical local meteorological data. These data will provide a means to estimate the dispersion of radioactive material due to accidental radioactive releases to the atmosphere by the plant. The acceptance criteria for meteorological measurements are described in the proposed Revision 1 to U. S. NRC Regulatory Guide 1.23.

Each site with an operating nuclear power plant shall have a viable backup meteorological measurements system. The backup system shall provide meteorological information when the primary system is out of service and, thus, assurance that basic meteorological information is available during and immediately following an accidental airborne radioactivity release. The acceptance criteria for the backup meteorological measurements system are described in the proposed Revision 1 to U. S. NRC Regulatory Guide 1.23.

Atmospheric Transport and Diffusion Assessment

Appendix E to 10 CFR Part 50 states that "(T)he means to be used for determining the magnitude of and for continually assessing the impact of the release of radioactive materials shall be described ..." To address this requirement, in part, all licensees with operating nuclear power plants shall provide the description of their system for making current, site-specific estimates and predictions of atmospheric effluent transport and diffusion during and immediately following an accidental airborne radioactivity release from the nuclear power plant. The purpose of these predictions is to provide an input to the assessment of the consequences of accidental radioactive releases to the atmosphere and to aid in the implementation of emergency response decisions.

Near real-time, site-specific atmospheric transport and diffusion models shall be used when accidental airborne radioactive releases occur. Two classes of models are appropriate. The first, Class A, is a model and calculational capability which can produce initial transport and diffusion estimates for the plume exposure EPZ within 15 minutes following the classification of an incident. The second, Class B, is a numerical model which represents the actual spatial and temporal variations of plume distribution and can provide estimates of deposition and relative concentration of radioactivity within the plume exposure and ingestion EPZs for the duration of the release.

The Class A model shall use actual 15 minute average meteorological data from the meteorological measurements systems maintained by the licensee. The selected data shall be indicative of the conditions within the plume exposure EPZ. The Class A model shall provide calculations or relative concentrations (X/Q) and transit times within the plume exposure EPZ. Atmospheric diffusion rates shall be based on atmospheric stability as a function of site-specific terrain conditions. Site-specific local climatological effects on the trajectories, such as seasonal, diurnal, and terrain-induced flows shall be included. Source characteristics (release mode, and building complex influence) shall be factored into the model. The output from the Class A model shall include the plume dimensions and position, and the location, magnitude, and arrival time of (1) the peak relative concentration and (2) the relative concentrations at appropriate locations. The bases and justification for these model(s) and input data shall be documented. The performance and limitations of the model(s) shall also be included in the documentation.

The essential elements of the input, of model components, and of output to be incorporated in the Class A model are given to provide guidance for meteorological system implementation. Additional guidance will be prepared to outline the staff position on dose assessment capabilities to be used for emergency response.

Remote Interrogation

Appendix E to 10 CFR Part 50 states that there shall be "(P)rovisions for communications among the nuclear power reactor control room, the onsite technical support center and the near-site emergency operations facility ...." There shall also be "(P)rovisions for communications by the licensee with the NRC Headquarters and the appropriate NRC Regional Office Operations Center from the nuclear power reactor control room, the onsite technical support center, and the near-site emergency operations facility" and "... among the nuclear facility, the principal State and local emergency operations centers ...."

To address this requirement with respect to the meteorological information, all systems producing meteorological data and effluent transport and diffusion estimates at sites with operating nuclear power plants shall have the capability of being remotely interrogated. This will provide current meteorological data and transport and diffusion estimates to the licensee, emergency response organizations, and the NRC staff, on-demand, during emergency situations.

Proposed Revision 1 to Regulatory Guide 1.23 identifies the meteorological data that shall be available. The information that shall be available from the transport and diffusion assessment include the model outputs, input variables, model identification and data source information, plant identification, and data from other sources, as available.

The capability to make transport and diffusion calculations with specific inputs shall be provided. The primary and backup communications systems shall have a data transmission rate of 1200 BAUD and the rate(s) and other specifications indicated in proposed Revision 1 to Regulatory Guide 1.23.

Documentation for procedures to access and use the system shall be provided to the emergency response organizations and the NRC, and shall be available in the control room, the Technical Support Center (TSC) and the Emergency Operations Facility (EOF).

ANNEX 1 TO APPENDIX 2

SCHEDULES TO IMPLEMENT THE METEOROLOGICAL ELEMENTS ADDRESSING EMERGENCY PLANNING RULES

Schedule for Operating Reactors -- For operating reactors the following implementation milestones shall be met to address the functional requirements.

Milestones are numbered and tagged with the following code; a-date, b-activity, c-minimum acceptance criteria. They are as follows:

(1) a. January 2, 1981
   b. Submittal of radiological emergency response plans
   c. A description of the emergency plan which addresses the meteorological functions shall be provided

(2) a. March 1, 1981
   b. Submittal of implementing procedures
   c. Methods, systems, and equipment to assess and monitor actual or potential offsite consequences of a radiological emergency condition shall be provided

(3) a. April 1, 1981
   b. Implementation of radiological emergency response plans
   c. Three functions of Appendix 2 with the exception of the Class B model of the assessment capability

Alternative to milestone (3) requiring compensating actions:

A meteorological measurements system which is consistent with the existing technical specifications as the baseline or a primary system and/or a backup system of Appendix 2, or two independent backup systems shall provide the basic meteorological parameters (wind direction and speed and an indicator of atmospheric stability) on display in the control room. An operable dose calculational methodology (DCM) shall be in use in the control room and at appropriate emergency response facilities. The following compensating actions shall be taken by the licensee for this alternative:

(i) if only a primary <u>or</u> a backup system is in use:

- The licensee (a person who will be responsible for making offsite dose projections) shall check communications with the cognizant National Weather Service (NWS) first order station and NWS forecasting station on a monthly basis to ensure that routine meteorological observations and forecasts can be accessed.
- The licensee shall calibrate the meteorological measurements at a frequency no less than quarterly and identify a readily available source of meteorological data (characteristic of site conditions) to which they can gain access during calibration periods.
- During conditions of measurements system unavailability, an alternate source of meteorological data which is characteristic of site conditions shall be identified to which the licensee can gain access.

- The licensee shall maintain a site inspection schedule for evaluation of the meteorological measurements system at a frequency no less than weekly.

- It shall be a reportable occurrence if the meteorological data unavailability exceeds the goals outlined in Proposed Revision 1 to Regulatory Guide 1.23 on a quarterly basis.

(ii) The portion of the DCM relating to the transport and diffusion of gaseous effluents shall be consistent with the characteristics of the Class A model outlined in the assessment capability of Appendix 2.

(iii) Direct telephone access to the individual responsible for making offsite dose projections (Appendix E to 10 CFR Part 50(IV)(A)(4)) shall be available to the NRC in the event of a radiological emergency. Procedures for establishing contact and identification of contact individuals shall be provided as part of the implementing procedures.

This alternative shall not be exercised after July 1, 1982. Further, by July 1, 1981, a functional description of the upgraded capabilities and schedule for installation and operation shall be provided (see milestones 4 and 5).

(4) a. April 1, 1982

b. Installation of Emergency Response Facility meteorological hardware and software

c. Three functions of Appendix 2, with exception of the Class B model of the assessment capability

(5) a. July 1, 1982

b. Full operation of milestone 4

c. The Class A model (designed to be used out to the plume exposure EPZ) may be used in lieu of a Class B model out to the ingestion EPZ. Compensating actions to be taken for extending the application of the Class A model out to the ingestion EPZ include access to supplemental information (meso and synoptic scale) to apply judgment regarding intermediate and long-range transport estimates. The distribution of meteorological information by the licensee should be as follows by July 1, 1982:

Meteorological Information	CR	TSC	EOF	NRC and Emergency Response Organizations
Basic Met. Data (e.g., 1.97 Parameters)	X	X	X	X (NRC)
Full Met. Data (1.23 Parameters)		X	X	X
DCM (for Dose Projections)	X	X	X	X
Class A Model (to Plume Exposure EPZ)	X	X	X	X
Class B Model or Class A Model (to Ingestion EPZ)		X	X	X

(6) a. July 1, 1982 or at the time of the completion of milestone 5, whichever is sooner

b. Mandatory review of the DCM by the licensee

c. Any DCM in use should be reviewed to ensure consistency with the operational Class A model. Thus, actions recommended during the initial phases of a radiological emergency would be consistent with those after the TSC and EOF are activated

(7) a. September 1, 1982

b. Description of the Class B model provided to the NRC

c. Documentation of the technical bases and justification for selection of the type Class B model by the licensee with a discussion of the site-specific attributes

(8) a. June 1, 1983

b. Full operation of the Class B model

c. Class B model of the assessment capability of Appendix 2

o <u>Schedule for Near-Term OLs</u>

For applicants for an operating license at least milestones 1, 2, and 3 shall be met prior to the issuance of an operating license. Subsequent milestones shall be met by the same dates indicated for operating reactors. For the alternative to milestone 3, the meteorological measurements system shall be consistent with the NUREG-75/087, "Standard Review Plan For the Review of Safety Analysis Reports for Nuclear Power Plants," Section 2.3.3 program as the baseline or primary system and/or backup system.

Appendix C

PROGRAM OF THE DECEMBER 1-3, 1981, NRC WORKSHOP ON METEOROLOGICAL ASPECTS OF EMERGENCY RESPONSE PLANS FOR NUCLEAR POWER PLANTS

Appendix C

PROGRAM OF THE DECEMBER 1-3, 1981, NRC WORKSHOP ON METEOROLOGICAL ASPECTS OF EMERGENCY RESPONSE PLANS FOR NUCLEAR POWER PLANTS

Tuesday, 1 December

SESSION I: INTRODUCTION

Welcome	EARLE D. JONES Vice President Advanced Development Division SRI International
Opening Presentation	BRIAN GRIMES Nuclear Regulatory Commission Office of Inspection & Enforcement
Consequence Scenarios and Sensitivities	JIM MARTIN NRC/Nuclear Regulatory Research
Emergency Action Levels	A.E. DESROSIERS Battelle/Pacific Northwest Laboratory
Emergency Response Facilities	STEVE RAMOS NRC/Inspection and Enforcement
Overview of Accident Assessments	BRIAN GRIMES NRC/Inspection and Enforcement

SESSION II: INTERFACE BETWEEN HEALTH PHYSICS AND METEOROLOGY

Keynote Presentation	NED HORTON General Electric
Meteorological Aspects of Particular Importance Health Physicists	MALCOLM PENDERGAST Savannah River Laboratory
Current Plume Model Methods	WALTER PASCIAK NRC/Nuclear Reactor Regulation
Surveillance Methods and Associated Uncertainties	EUGENE BATES NRC/Inspection and Enforcement

SESSION III: INTERFACE BETWEEN RELEASE CHARACTERISTICS AND METEOROLOGY

Keynote Presentation: Overview of the Interface Between Release Characteristics and Meteorology	WILLIAM KREGER NRC/Nuclear Reactor Regulation
Release Characteristics from a Spectrum of Accidents	JIM MARTIN NRC/Nuclear Reactor Regulation
Release Characteristics and Atmospheric Dispersion	RAY HOSKER (Presented by BRUCE HICKS) NOAA/Atmospheric Turbulence and Diffusion Laboratory
Utilization of Operational Meteorological Systems Data	IRWIN SPICKLER NRC/Nuclear Reactor Regulation

SESSION IV: SPECIAL CONSIDERATIONS OF TRANSPORT, DIFFUSION, AND DEPOSITION

Keynote Presentation: Overview of Transport, Diffusion, and Deposition	BRUCE HICKS NOAA/Atmospheric Turbulence and Diffusion Laboratory
Atmospheric Transport	J.V. RAMSDELL Battelle/Pacific Northwest Laboratory
Atmospheric Diffusion	ISAAC VAN DER HOVEN NOAA/Air Resources Laboratory
Deposition	TERRY DANA Battelle/Pacific Northwest Laboratory

Wednesday, 2 December

SESSION V: PANEL DISCUSSION ON OPERATIONAL ASPECTS

Moderator:

SCOTT LEIPER
Atomic Industrial Forum, Inc.

Participants:

MALCOLM PENDERGAST
Savannah River Laboratories

MARV DICKERSON
Lawrence Livermore Laboratory

GENE START
National Oceanic and Atmospheric Administration

THOMAS SOWDON
Boston Edison

WILLIAM RIETHLE
Metropolitan Eidson/TMI

GEORGE W. REYNOLDS
Tennessee Valley Authority

RICHARD H. THUILLIER
Pacific Gas and Electric Company

INITIAL WORKING GROUP MEETINGS

WORKING GROUP A: Health Physics and Meteorology

WORKING GROUP B: Release Characteristics and Meteorology

WORKING GROUP C: Dispersion and Deposition

WORKING GROUP SESSIONS

Thursday, 3 December

PREPARATION OF PRELIMINARY WORKING GROUP RECOMMENDATIONS

PLENARY SESSIONS

PREPARATION OF FINAL WORKING GROUP RECOMMENDATIONS

Adjournment

Appendix D

EXTENDED ABSTRACTS* OF INVITED TECHNICAL PRESENTATIONS

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*Available abstracts are reproduced here in original, unedited form and reflect the individual views of the authors and not necessarily those of the Workshop as a whole.

LWR ACCIDENT SPECTRUM - RELEASE CHARACTERISTICS AND CONSEQUENCES*

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Washington, DC 20555

Possible releases of radioactive materials from light water nuclear power reactors (LWRs) range from the routine and benign to the catastrophic and deadly, with likelihood (or probabilities) ranging from unity (routine releases) to very small (catastrophic releases). Before TMI the latter types of accidents were not explicitly considered in the AEC and NRC licensing process. Since TMI, the potential for the high (off-site) consequence accidents are being considered explicitly in numerous licensing areas, notably in off-site emergency planning. The demarkation is the current explicit consideration of those accidents which include major or massive containment failures.

The problem, of course, is the enormous amount of volatile radioactive species present in the core of an operating LWR and the power in the decay heat (after shutdown) available to drive this material from the core into the environment. Shutdown decay heat is of the order of three to five percent of full power during the first hour after shutdown. For a 3300 megawatt-thermal (MWT) reactor, initial decay heat is an impressive 150 MWT--a substantial driving force if not controlled. (Vaporization of water at a rate of about 1000 gal/min could remove this decay heat and protect the core, by the way.) The in-core activities of volatile species are impressive also. The billion, or so, curies of these species (one half hour after shutdown) can be broken down roughly as follows:

300 million (M) curies of noble gases;
600 M curies of radioiodines;
130 M curies of tellurium-132;
30 M curies of ruthenium-106;
20 M curies of radiocesiums;

and a host of other radioisotopes in substantial abundance. These are the potential radiological source terms.

It is instructive to compare these inventories to the activity required to be released to induce doses equal to Protective Action Guides. For a x/Q' of 10^{-4} sec/m^3, the following table can be constructed:

PAG (rem)	Q (curies)	Organ/Pathway
5	1,500,000	Whole Body/Cloud (External) Gamma
25	600 (I-131)	Thyroid/Inhalation by Child
15	2 (I-131)	Thyroid/Air-Posture-Cow-Milk-Ingestion by Child

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* Combines Mr. Martin's two Workshop presentations: "Consequence Scenarios and Sensitivities," and "Release Characteristics from a Spectrum of Accidents."

Thus, a release of only very small fractions of the core inventory would be needed to result in doses exceeding PAGs in the near field off-site. However, only irradiated fuel and primary cooling water contain the requisite inventories. No other system failures would induce a PAG. Thus, where current PAGs are planned as triggers for protective actions off-site, only the reactor core, the spent fuel storage pool and the primary water should be of concern and a loss of coolant accident (LOCA) or the significant threat thereof would be a necessary precursor to protective action off-site. The fuel in the fuel storage pool is cool to start with, of course, so the primary concern from a PAG perspective is the core.

(One caveat is important: The U.S. Food and Drug Administration (FDA) has proposed a preventive PAG of 1.5 rem for the milk pathway, for which dairy animals should be removed from likely or actually contaminated pasture. Catastrophic accidental releases of I-131 from the waste gas storage tank at a PWR site, or the effluent treatment system at a BWR, could result in pasture contamination leading to such a PAG, especially during a period of precipitation.)

The masses of various materials that could be involved in a core melt accident may be of interest also:

H_2O	2×10^5 kg
UO_2	10^5 kg
Zr (clad)	2.0×10^4 kg
Sn (clad)	300 kg
Fe (structure)	2.5×10^3 kg (in core) 2.5×10^4 kg (core + bottom structure)
I	18 kg
Cs	255 kg
Ba, Sr, Mo	416 kg
Zr (Fission Product)	276 kg
Ru, Rh, Pd, Te	318 kg

and smaller masses of other radionuclides. (Silver in control rods is receiving increased attention currently because of its low melting point and volatility at high temperatures.)

Many chemical forms of these materials would be present in a core melt scenario--gases, vapors, particulates, soluble and insoluble forms are possible in many combinations. The radioiodines and cesiums are of special concern because of their volatility and high consequence potential. (Noble gases are relatively innocuous.) A noteworthy complicating factor in this regard is the decay chain Te, I, Xe, Cs, Ba, La - a halide (I) decays into a noble gas (Xe), which decays into an alkali metal (Cs). The matter is extremely complicated, but an important current consensus is that in an aqueous environment, even at high temperatures, I and Cs would exist as I^- and Cs^+ ions dissolved in water and in a dry system I_2 would be the dominant form of iodine. Many interesting reactions involving steel, paint, hydrogen, lubricants (oils), steam and high temperatures which produce organic iodines (e.g., gaseous CH_3I) have also been noted. If released to the atmosphere, CH_3I could decompose in sunlight to form I_2, however; the phenomenon has been observed, but little is known about it.

The distribution of particle sizes is also of interest. Very little hard data is available in this regard. What is known can be succinctly stated: insoluble materials rapidly agglomerate to diameters in the range 0.5 to 2. microns, with log-normal distributions of geometric standard deviation in the range 1.5 to 1.8. In an aqueous (steam) environment in a containment these particles act as condensation nuclei for the formation of water droplets, the sizes of which are in the range 10 to 20 microns. Settling of larger droplets acts to cap the size. This information pertains to intact containments and the atmosphere within a steamy containment. Interestingly, fog and a definite violet tinge has been observed at high I_2 concentrations in such an environment. Very little is known in the reactor community regarding the particle size distributions that would be evident in the atmosphere in failed containment scenarios. Evaporation of droplets of hot water released (blown out) to the atmosphere would leave residual particles of speculative size but probably less than several microns. For intact containments, only very small (sub-micron) sized particles would be released to the atmosphere; most likely, only the noble gases would be released in significant abundance, over a long term, a la the TMI accident.

Before proceeding to a discussion of major accident sequences and consequences thereof, it is worthwhile, even necessary, to establish a perspective regarding their probability or likelihood. Succinctly, the likelihood is very low for a single reactor and for the industry in any year. The calculated probability per reactor year projected over the lifetime of the current industry is also low, but there is a large uncertainty in the current estimates. The current status is illustrated in Figure 1, in which release fractions of the core inventory for various accidents are plotted against the calculated probability of such releases. The data points displayed are taken from the Reactor Safety Study (WASH-1400) and are illustrative only since they may or may not truly represent the current industry, post TMI fixes. The following comments on this data and its importance are a fair representation of the current estimates, none-the-less. It is obvious from the figure that the probabilities of major release fractions are at or below about $2x10^{-5}$ per reactor year. It is extremely difficult to cope with such small numbers. Assuming 100 reactors of current vintage operating for 40 years each (the current industry), and a probability of a major release of $2x10^{-5}$ per reactor year, the probability of a major release during the life of such an industry would be 0.08, or 12:1 <u>against</u> such an occurrence. This is a not uncomfortable prospect. Unfortunately, the uncertainty in the basic probability estimate is very large, off-times quoted as at least an order of magnitude either way. Thus, the calculated chance of a major release in the U.S. over the life of the industry is in the range between virtual certainty and at least 100:1 against. This estimate does not include considerations of sabotage and certain external events, e.g., massive earthquakes.

It is also worth noting that the large release fractions (0.1 to 0.8) of the core inventory as presented in Figure 1 have been strongly attacked as being unrealistically high. Considerable efforts are underway at this time (ca.

early 1982) to assess the potential release fractions more realistically. For scoping purposes, it is merely noted here that certain potential release fractions can hardly increase significantly (from, e.g., 0.8) and that a reduction by a factor of ten to twenty would virtually eliminate the chance of early death and injury as consequences of LWR accidents, assuming only a modicum of leisurely protective actions off-site.

Catastrophic decompression of a containment would result in the release of large amounts of water, at least, at sonic velocities (choked flow). Depending on the location of the break and the initial trajectory of the release (up or down), plume rise up to 600 meters, or so, is possible, but the range 10 to 200 meters is more likely. Release rates as high as 2×10^5 gram/sec (H_2O) have been estimated. It is not known whether or not the water would flash to vapor in the atmosphere, or agglomerate into drops large enough to settle out. Mass loadings could be as high as 20 grams (H_2O) per M^3 (air) at a mile or so, i.e., at the saturation point at STP. (A deep sea fog contains 1 to 3 grams H_2O per M^3 air.) Explosive decompression would be spectacular, of course. The leading puff release could last from minutes to tens of minutes, depending primarily on the magnitude of the driving pressure and reservoir. The puff release of water could contain anywhere from very little of the core inventory to major fractions of the core inventory of radionuclides, depending on the accident sequence (loss of water before or after core damage or melt).

Patently, if a containment does not fail catastrophically, longer duration releases (a la TMI) would result. These releases would be gases and vapors, predominantly. However, daughter products of the noble gases and condensible vapors would be attracted to atmospheric particles, most likely in the submicron range (0.1 micron or less) where the available number density and surface area (for condensation) is highest. These daughter products are relatively short lived (fourty minute half-life, or less, e.g., Rb-88 and Cs-138). The capture of these particulate daughter products in air samplers could prove misleading to the unwary.

Many containment failure/core melt scenarios can be postulated, but four sequences encompass the various possibilities:

- o core melt/melt-through of basemat
- o core melt/containment failure by overpressure
- o containment failure by overpressure/core melt
- o containment by-pass/core melt

The first two of these are notorious. The first is the "china syndrome" accident where the core melts through the concrete base and enters the ground. Pressure relief is via tunneling of water, steam, etc. to the surface, with a ground level release, or only a small plume rise. This would be a dirty release and should be obvious. There is a good chance, however, that only invisible noble gases would percolate to the surface. Time delays after melting of the core through the steel pressure vessel to the basemat could range from hours to days - and never in some cases. Failure of containment heat removal systems during this sequence could (would in small containments) result in containment fracture, or catastrophic failure resulting in a rapid blowdown. A one square foot hole, e.g., a 2" x 6' crack, would result in a blowdown (blowout) in a half hour, or less. Operability of containment sprays and filters would influence (reduce) releases to the environment, but the results would be messy, none-the-less, because of flashing of steam and water aerosols carrying radioactivity. A very large (200 meters) visible plume rise could result if the release were to be directed upward. Rainout from the plume (puff) is possible. Substantial deposition near the source and a moderate plume rise could result for a downward directed release. Major fractures below the water line would release the largest fraction of the available activity (curies). The smaller the crack or opening above the water line the larger the resulting ratio of noble gas to other species of materials, and the slower the release. In general, the less water that is flashed or otherwise projected to the atmosphere, the greater should be the ratio of noble gases to other species, and the less the consequences off-site.

The last two sequences listed above would involve containment failure before core melt. Both would involve major losses of low activity coolant to the atmosphere initially, but with possibly significant differences in off-site consequences due to the different potentials for internal scrubbing via natural processes. The third sequence could result from a failure to scram (trip, shut off) the reactor upon containment isolation, the dumping of large amounts of power into the containment (more than the containment heat removal systems could handle) and containment failure due to overpressure. The resulting massive loads could cause a massive LOCA, or LOCAs, and core melt. Relatively large fractions of the radioactive material released from the core could remain in containment deposited on various surfaces because of the relatively lower driving force (i.e., loss of pressure before melt). Major releases at ground level could result, nevertheless, but less than that produced when a strong driving force exists on radioactive material per se.

The fourth scenario is called the interfacing systems LOCA, or Event V in the Reactor Safety Study where it was first identified. In this scenario the primary cooling water blows down via a failure in isolation valves separating the 2000 psi primary system (PWR, BWR pressure is 1000 psi) and a low pressure system (e.g., RHR system at 100 psig). This blowdown bypasses containment entirely. There is enough potential energy to actually destroy the auxiliary building if released in a short time (one-half hour or less). The core then melts, releasing materials at a rate proportional to volatility (i.e., in sequence, noble gases, iodines and cesiums, etc. with some mixing). It is currently assumed that because of the high heat these volatiles escape to the atmosphere without significant plateout in the plumbing. There is a possibility, being investigated, that the driving forces for these volatiles would not be sufficient to prevent substantial plateout, resulting in a smaller (yet substantial) source term. Vapors released to the atmosphere would eventually condense on atmospheric particles (and possibly some core matter). This would be a short duration, also spectacular, accident with potentially very high consequences because of the short (no) warning time before release. Although the initial blowdown could result in a moderate plume rise of the relatively low activity water, the high activity releases could be near or at ground level. Since the identification of this sequence, quality assurance on the interfacing systems has been intensified to reduce its likelihood substantially.

Many other types of accidents can occur, of course, but unless irradiated fuel is damaged, radiation exposures off-site should be well below that necessary to induce a dose for which there would be a detectable radiation effect in the human body. As noted above, PAGs should not be exceeded unless damage to irradiated fuel or a LOCA occurs. Nevertheless, emergencies may well be declared for non-LOCA or fuel damage accidents, hearings may be held, fines assessed, and reports written in response to such accidents of lesser importance. Part of the record may be an assessment of doses and contamination levels in the environment, for which meteorological information will be used, at least in part. It must be recognized, however, that for such events the collective (population) dose, i.e., the man-rem, or person-rem, may well be the prime issue. Latent cancers and genetic effects are functions of the collective dose. It is important to recognize that such doses occur predominantly where the people are, which is predominantly far from the source of the release - often between twenty and 100 miles from the source. Thus, regional meteorology during the period of release and subsequent transport, rather than site meteorology, would be the prime meteorological concern. Site meteorology during the period of release would be used, in part, to assess conformance with pertinent regulations regarding doses at or near the site boundary, i.e., 10 CFR Part 20, Appendix I to 10 CFR Part 50, 10 CFR Part 100 (NRC Regulations), and 40 CFR Part 190 (EPA Regulation). For such assessments, numerous dosimeters are currently required in the site environs to provide a direct measurement of external (cloud) gamma dose (and "shine" dose). Air samplers are also required in the environs, but there is an excellent chance that any release would miss these fixed samplers. Many small accidents would result in puff releases, and would be long gone before portable air samplers could be fielded. Thus, site meteorology would be important to assess inhalation exposures nearby resulting from small releases. Since small accidental releases are virtually certain, whereas large releases are speculative, it may well be the case that the site meteorological data will find its most important use in demonstrating that pertinent regulations are not violated.

Given an accidental release in-plant or on-site, which results in a release to the atmosphere, there may or may not be a measured release or release rate available (i.e., a source term). Consequences of non-core-melt accidents will be discussed first. Most releases in-plant should be released, if at all, through engineered safety features (e.g., filters) and past or through radiation detectors. Two aids would be available in this case: source terms should be small and dominated by noble gases, and a measured release rate would be available. An exception could occur if the source of a release is aged spent fuel in the spent fuel storage pool (SFSP). In this case weak gamma and beta emitting longer-lived noble gases (Xe-133 and Kr-85, respectively) could be mixed in roughly equal proportions (curies) with other volatile species (I, Cs) and a source term may not be known, especially in older LWRs. Normally, if a source term has been measured, that release can be assumed (at least initially) to have passed through engineered safety features, lacking any evidence to the contrary.

Some smaller accidents could result in a release that by-passes monitored release paths. Most of the potentially more serious non-core-melt accidents would fall in this category. The consequences of such accidents are assessed using very conservative assumptions in Safety Analysis Reports (SARs) for all but the very oldest LWRs. A typical table in an SAR would appear as follows:

Infrequent Accidents	Duration of Release	Dose (rem) at 2206 meters* Thyroid	Dose (rem) at 2206 meters* Whole Body
Radioactive Waste System Failure	2 hrs	0.1	0.1
Steam Generator Tube** Rupture	2 hrs	13	1.0
Fuel Handling Accident	2 hrs	2.1	0.044
Limiting Faults**			
Main Steam Line Break	2 hrs	79	1.0
Large-Break LOCA	2 hrs	85	1.2

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*The site boundary distance which yields the highest radiological dose following the postulated accident.

**These presume some fuel failures as part of the scenario.

Such information could be used to scope the potential consequences, recognizing the extreme conservatisms in the assumptions and calculations performed before the fact. The various assumptions are listed in SARs. One conservatism, the use of the "semi-infinite" dose factor for external (cloud) gamma whole body dose is noteworthy. The use of this dose model tends to overestimate the whole body dose by a factor of 5 to 20 for the meteorological conditions assumed during the release period (e.g., Pasquill Class F stability, 1 meter/sec wind speed). Consequences of accidents of this ilk would involve the inhalation and contamination pathways predominantly. From a meteorological standpoint, the trajectory of such releases, ground level puffs for the most part, would be of paramount concern, mostly for the initial direction of site and off-site radiological survey terms. Diffusion should be of secondary concern initially, since the lack of a source term would prohibit an accurate dose calculation. (Although this is certainly true, quesstimates of dose would undoubtedly be made to satisfy craving appetites. For such gross estimates visual observation of local weather conditions should suffice to estimate the stability class at the time and pre-calculated doses and dose rates for various scenarios would be useful assessment aids.)

Consequences of releases of major fractions of the core inventory of volatile radioactive species to the atmosphere would be severe, widespread, far-reaching and long lasting. From a meteorological and protective action standpoint, it is extremely important to recognize the high worth of the ground contamination pathways as compared to the cloud (external) gamma and inhalation pathways. An appreciation of this perspective can be gained by a perusal of the information displayed in Figure 2 and Table 1. Figure 2 illustrates the calculated contribution of various nuclides to whole body dose, by three major pathways, at a range of one-half mile, for one postulated core melt scenario (the BWR-1 release from the Reactor Safety Study). Average whole body dose contributions are displayed, as calculated for 91 different weather sequences. The time scale on the horizontal axis pertains to the inhalation pathway only, and merely indicates that the whole body dose after inhalation monotonically increases somewhat over a period of time as the radioactive material in the body releases its energy. The important meteorological perspective is that the contributions of dose via the three pathways (inhalation, cloud (external) gamma, and ground contamination) are about equal (one-third each) on the average at short range for these scenarios. This is for a four hour exposure to ground contamination. Patently, the longer the ground exposure, the larger the relative worth of the ground contamination pathway.

The relative importance of deposition from the atmosphere to the ground pathways, for releases of mixed chemical species, increases with distance from the source. This is illustrated in Table 1 which shows the various contributions to latent cancer production by various organs and pathways for another postulated accident (the PWR-2 release of the Reactor Safety Study). Perusual of the data in this table will impress the significance of the ground pathways. Even for the immediate period of plume (puff) traverse, the cloud gamma pathway contributes only about 5 percent of the total calculated latent cancers. In the long term this pathway contributes only about 1 percent of the insult. These are long range and long term effects; the ground pathways dominate the insult because of the long exposure times involved.

Intercept of precipitation and plume (puff) traverse could increase the relative worth of the ground pathways for a mixed species release. After the composition of the source term and the release trajectory, precipitation could well be the next most important parameter of concern in an actual release situation. As illustrated in Figures 3, 4, and 5, precipitation within ten miles of a release point could dominate the magnitude of the consequences, as compared to many other meteorological variables.

Although not shown explicitly in any of these displays, the coincidence of a major mixed species release, precipitation, a calm and a major populated area would induce amongst the highest consequences in accident/release scenarios, in terms of the number of persons affected and the value of the property damaged. Calms at the point of a release could be beneficial. A calm after some traverse at nominal wind speeds (5-10 mph) could result in high consequences. In some respects, a calm downwind of a release, or precipitation, could be beneficial, e.g., if they occur in unpopulated areas. But precipitation along the plume traverse has the clear potential for contaminating surface and ground water, as well as surfaces. Surface waters could carry contamination hundreds of miles from a release point, requiring, as a minimum, sequential shutdown of water intake pumps at municipalities downstream. (Restart of pumps after a short period might well be possible for a slug impact.)

From an overall perspective standpoint, the insensitivities of certain important consequences to annual average meteorology is worth noting. To examine this matter, hourly data from twenty-nine weather stations across the United States were used for consequence calculations. Consequences were calculated assuming a mix of major release core melt scenarios (10^{-4} to 10^{-5} per reactor year probabilities). The results are summarized in the three figures in Figure 6. In these figures, the magnitudes of the calculated consequences are displayed as a function of the probability of a consequence of certain magnitude. The calculations were performed for two sites: the heavily populated Indian Point site about thirty-five miles north of New York City on the Hudson River, and the Diablo Canyon site near Santa Barbara, California, for which there are no residents within five miles of the site. As is readily apparent from the Indian Point figures, the results of the early death and latent cancer fatality calculations are particularly insensitive to weather sequences except at the low probability, higher consequence portions of the curves. Because of the lack of residents close to Diablo Canyon, the conditional probability of an early death is much lower than that at Indian Point, by some two orders of magnitude, in fact. Since the chance of an early death beyond five miles is low to begin with, the Diablo Canyon results are in many ways an amplification of the tails of the Indian Point figures, where low probability coincidences of population, calms and precipitation (as well as the source term) govern the results. Note that the conditional probabilities in the figures should be reduced by a factor between 10^{-4} and 10^{-5} to arrive at an absolute probability estimate. These are indeed low probabilities. As displayed in the latent cancer figure, different meteorological sequences produce very little differences in latent cancer production, as noted above. The same result pertains for chronic releases - annual collective dose depends almost solely on curies released and total population, and has little to do with annual wind roses or weather sequences. It's also a far-field (long range) effect - man-rem accumulates where the people are.

Thus, consequences depend predominatly on the magnitude of a release and the release trajectory during transport, and where the people are located. Calms and precipitation are important also. For release scenarios which do not begin until a few hours after the declaration of an emergency, the meteorological information of importance would be weather projections, for the most part, rather than the site meteorological information per se.

All-in-all, site meteorological information would be of most value in the event of a selected few accident sequences or scenarios for which it would be possible to project or calculate a near-field dose (one objective), i.e., a source term would be available. Otherwise, the dose and dose rate objectives would be accomplished by utilizing near-field dosimetry augmented by data collected by monitoring teams. To satisfy the second dose objective, the collective dose (far-field) calculation, regional meteorology and transport codes would have to be used, also supplemented by data from mobile radiological monitoring teams. This would not be a short term need, however.

Finally, certain aspects of the hourly wind rose and accident and protective action sequences during the TMI accident are worth discussion. Figure 7 presents the hourly wind rose as measured at the site during the first day. Because of a computer crash, this data was not obtained until several days after the accident-verbal reports from the site were obtained throughout the time period, however. Note that the wind direction at the site varied continually for over 12 hours before becoming steady during the night. The variability of direction is characteristic of the light (wispy) winds during the day. It is especially noteworthy that between 7:30 a.m. and 8:00 a.m. warnings of imminent evacuations to the west of the site were made by the State (PA). At 8:10 a.m. this preparedness was reduced to a standby notice because dose rate measurements to the west were "only" one mR/hr. This was just at the time the core was uncovered by several feet, or so! Further, even had an evacuation to the west of the site been initiated at 8:00 a.m., or so, by 9:00 a.m. the wind has shifted to the north! As noted by the NRC Special Inquiry Group, the evacuation of the Low Population Zone (2.5 radius area surrounding the site) should have been completed based on in-plant observations, as was set forth in the emergency plans, and as emphasized in current NRC emergency planning guidance. This is especially noteworthy because the current NRC protective action guidance is based on two imminently reasonable guidelines: do not plan to send people outside if heavily laden plumes are in the area, and do not plan to await an actual major release to the atmosphere before recommending protective actions to people. These two fundamentals underlie the Emergency Action Level and pre-determined protective action concepts developed before and since the TMI accident. From a dose projection meteorological standpoint, this means that the plans are laid with the explicit understanding that projected doses would most likely not be known or very low when protective actions would be recommended. This fundamental perspective limits both dose projection and meteorological needs for short term, short range protective action decisions. These needs would have to be satisfied for longer term, longer range projections, however. During TMI, the evacuation recommendation which did occur was made predominantly on the basis of in-plant uncertainties and public concern as compared to dose projections (and meteorology). The assessment of projected health effects, calculated the first day and reported days and weeks later, did utilize site and regional meteorological data to buttress the off-site dosimetry data. This sequence is virtually planned for the future, albeit with (hopefully) better coordination and more timely actions and results, if needed.

BIBLIOGRAPHY

Reactor Safety Study. WASH-1400 (NUREG-75/014), USNRC, October 1975 (n. b. Appendix VI - Calculation of Reactor Accident Consequences).

Wall, I. B., et al., Overview of the Reactor Safety Study Consequence Model, NUREG-0340, USNRC, June 1977.

Technical Basis for Estimating Fission Product Behavior During LWR Accidents, NUREG-0772, USNRC, June 1981.

Aldrich, D. C., et al., Sandia National Laboratories. *Examination of Offsite Radiological Emergency Protective Measures for Nuclear Reactor Accidents Involving Core Melt*, NUREG/CR-1131, USNRC, June 1978.

Aldrich, D. C., Impact of Dispersion Parameters on Calculated Reactor Accident Consequences, SAND79-2081, Sandia National Laboratories, Albuquerque, NM, November 1979.

Martin, J. A., Jr., Perspectives on the Role of Radiological Monitoring in an Emergency, Trans American Nuclear Society, v. 34, pp. 727-729, June 1980, (available from author, USNRC).

Technical Guidance for Siting Criteria Development, NRUEG/CR-2239, USNRC, in preparation, January 1982, (estimated availability date May 1982).

R. K. Hilliard and L. F. Coleman. Natural Transport Effects on Fission Product Behavior in the Containment Systems Experiment. BNWL-1457. Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, WA 99352. December 1970.

Nuclear Aerosols in Reactor Safety. Nuclear Energy Agency/Organization for Economic Co-Operation and Development. 2, rue André-Pascal, 75775 Paris Cedex 16, France. (In english.) June 1979.

Proceedings of the CSNI Specialists MEeting on Nuclear Aerosols in Reactor Safety. NUREG/CR-1724. USNRC, Washington, D.C. 20555. (In english.) October 1980.

Handbook on Aerosols, R. Dennis, ed. TID-26608. NTIS, U.S. Dept. Commerce, Springfield, VA 22161. 1976.

Table 1 Contribution of Different Exposure Pathways to Latent Cancer Fatalities for a PWR-2 Release Category*

Percentages

	Leukemia	Lung	Breast	Bone	GI Tract	All other	Total	Whole Body
External Cloud	.2	.1	.5	.1	.1	.1	1	1
Inhalation from Cloud	.5	4	.7	.2	.4	.2	6	3
External Ground (< 7 days)	3	2	7	.7	.9	3	16	16
External Ground (> 7 days)	12	8	28	3	4	11	66	68
Inhalation of Resuspended Contamination	.2	1	.2	.4	.2	.1	3	2
Ingestion of Contaminated Foods	2	1	3	1	1	1	9	10
SUBTOTALS	18	16	39	5	6	16	100	100

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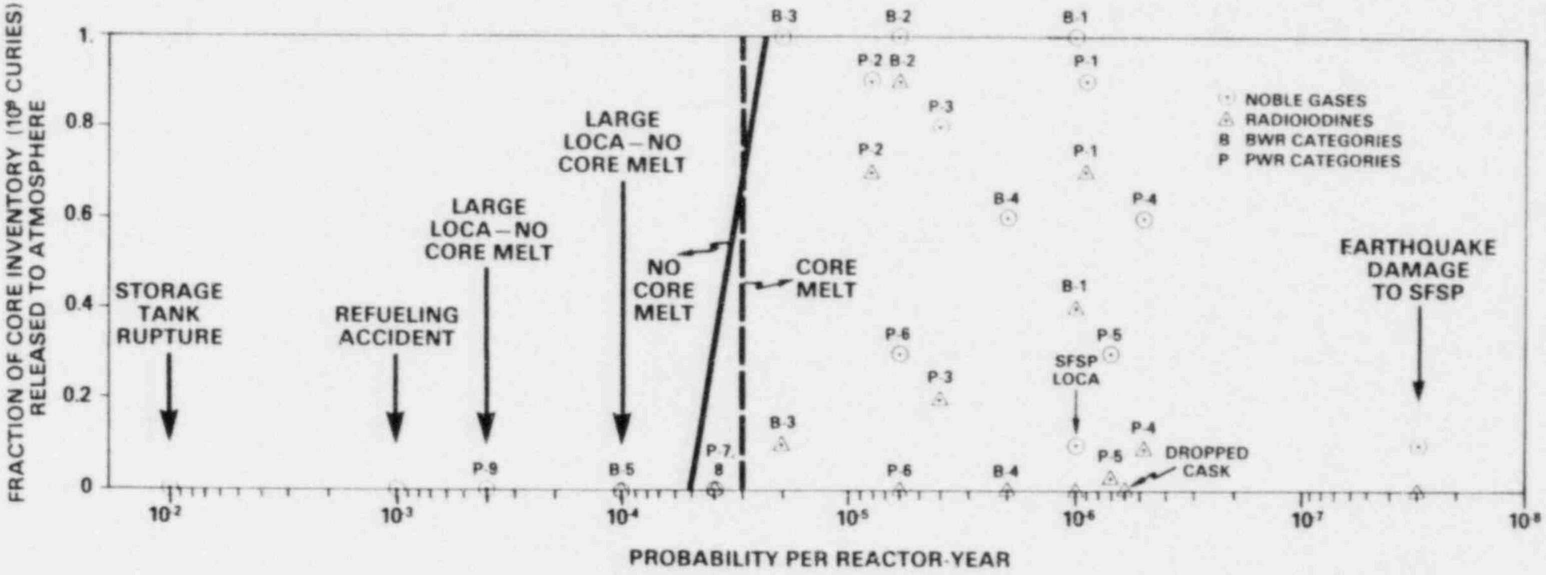
*Except thyroid cancer, which is calculated separately.

FIGURE 1

RELEASE FRACTIONS VS. PROBABILITIES FOR NUCLEAR POWER PLANT POSTULATED ACCIDENTS —FROM TABLES V2-1 AND V2-2 OF WASH-1400 (REACTOR SAFETY STUDY)



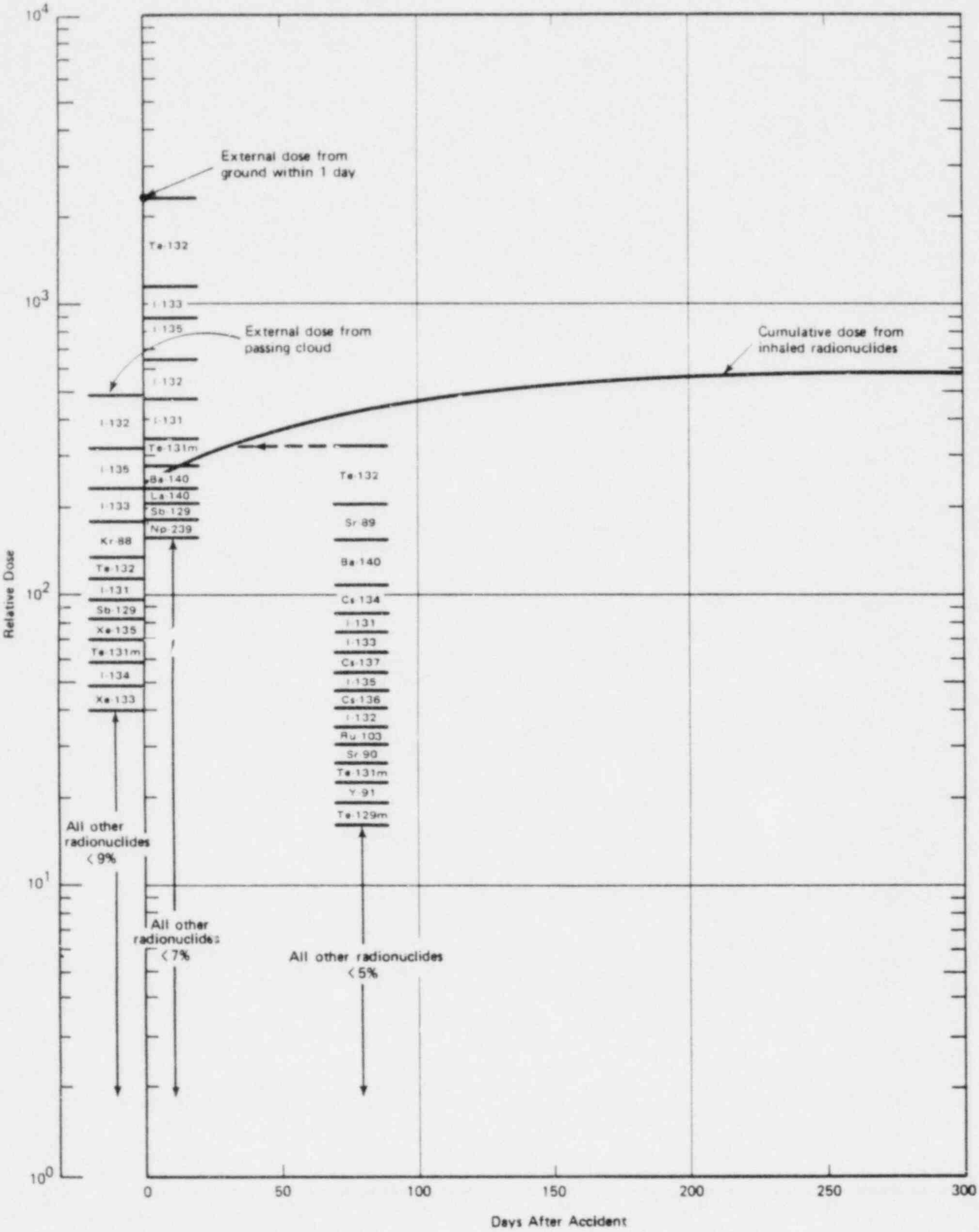


FIGURE 2 Relative doses to bone marrow at 0.5 miles from reactor.

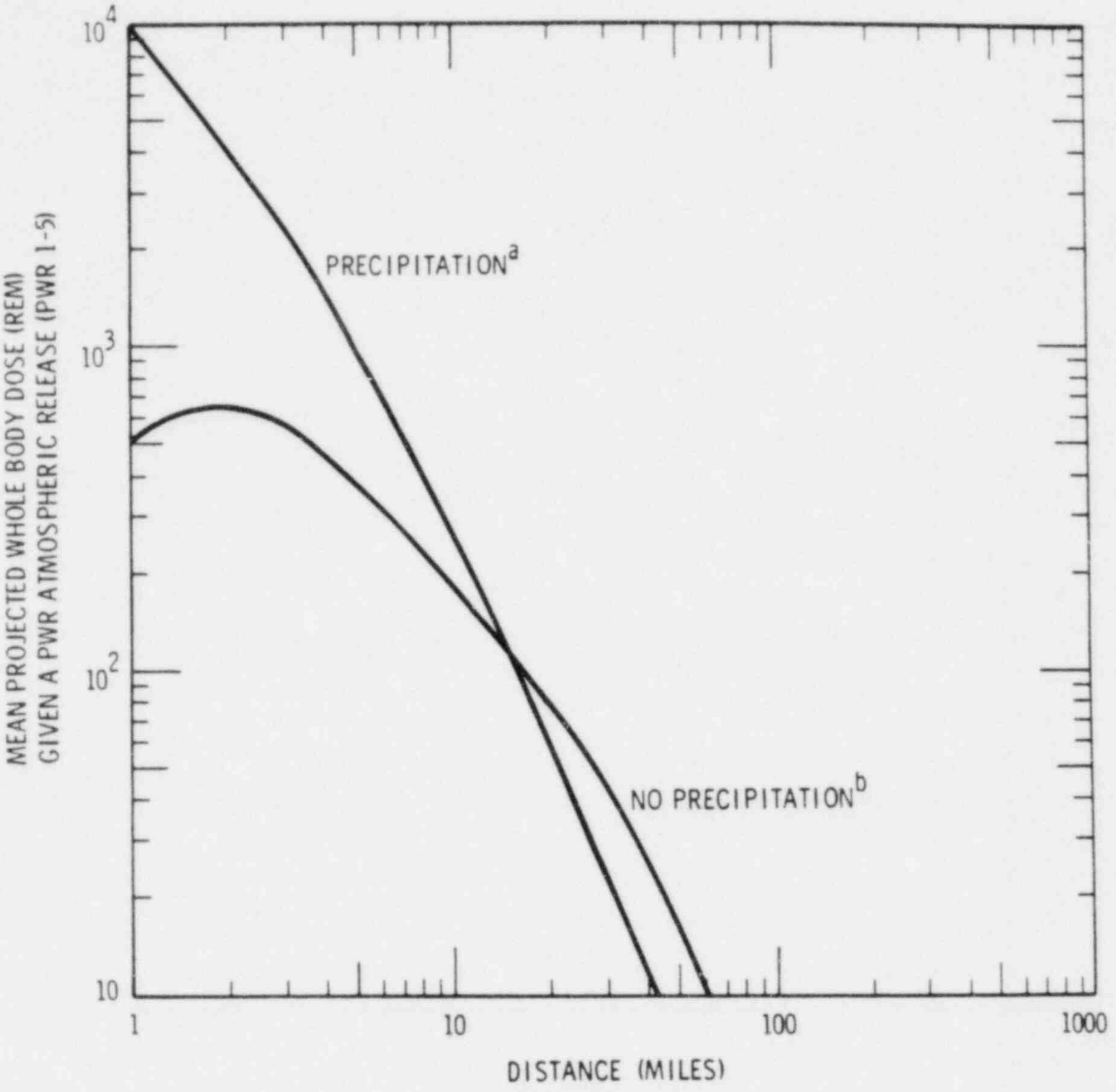


FIGURE 3 Comparison of Mean Projected Whole Body Dose Versus Distance for Accidents in Which Precipitation[a] and No Precipitation[b] Conditions Exist at the Start of Release. Projected Doses are for an Individual Located Outdoors,[c] and are Conditional on a PWR "Atmospheric" Release (PWR 1-5).

[a] Accidents in which it is precipitating (rain or snow) at the start of release.

[b] Accidents in which it is not precipitating (rain or snow) at the start of release.

[c] Shielding factor for airborne radionuclides = 1.0. Shielding factor for radionuclides deposited on ground = 0.7. 1-day exposure to radionuclides on ground.

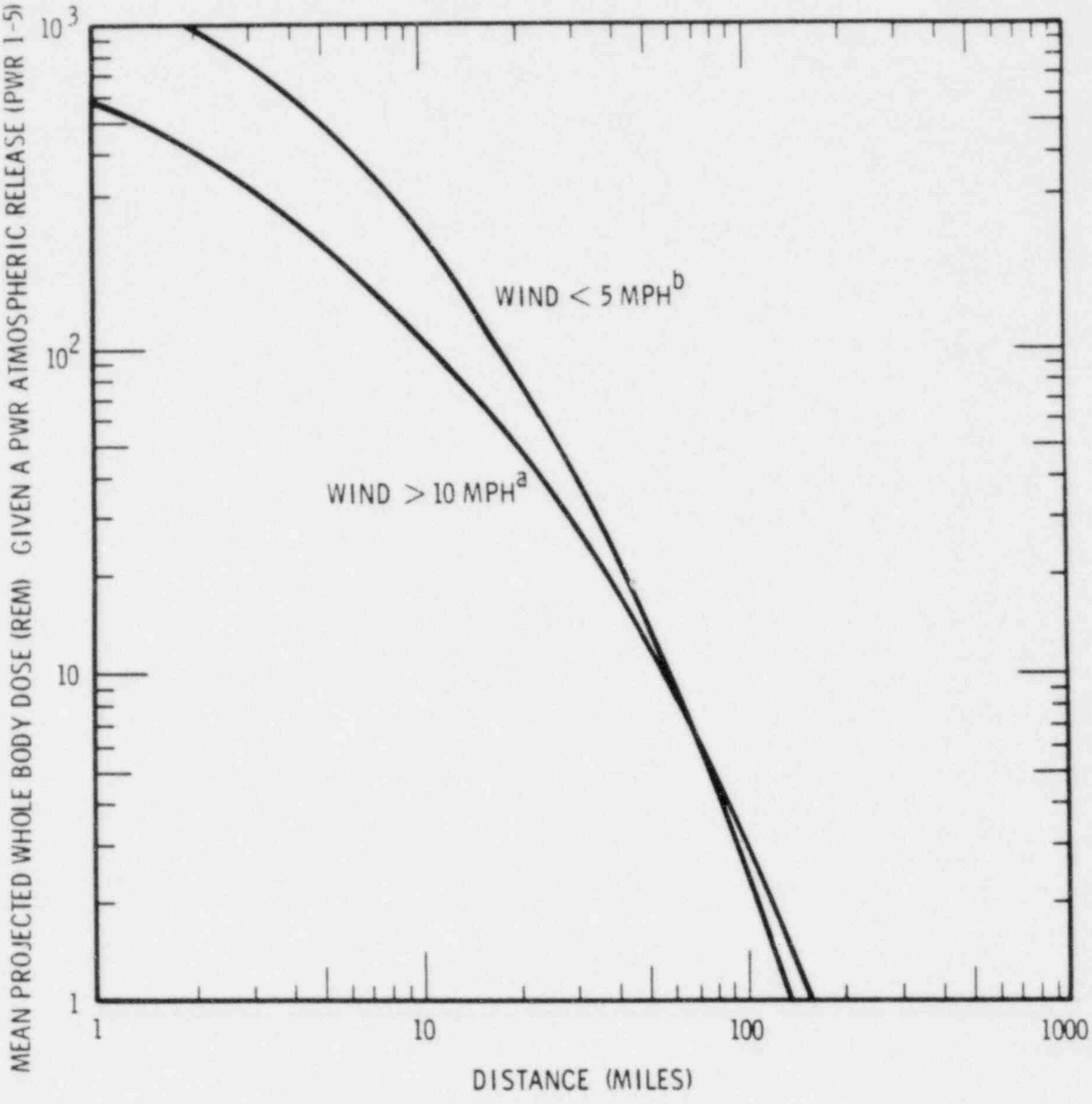


FIGURE 4 Comparison of Mean Projected Whole Body Dose Versus Distance for Accidents in Which High Wind[a] and Low Wind[b] Conditions Exist at the Start of the Release. Projected Doses are for an Individual Located Outdoors,[c] and are Conditional on a PWR "Atmospheric" Release (PWR 1-5).

[a] Accidents in which the windspeed is greater than 10 MPH at the start of release.

[b] Accidents in which the windspeed is less than 5 MPH at the start of release.

[c] Shielding factor for airborne radionuclides = 1.0. Shielding factor for radionuclides deposited on ground = 0.7. 1-day exposure to radionuclides on ground.

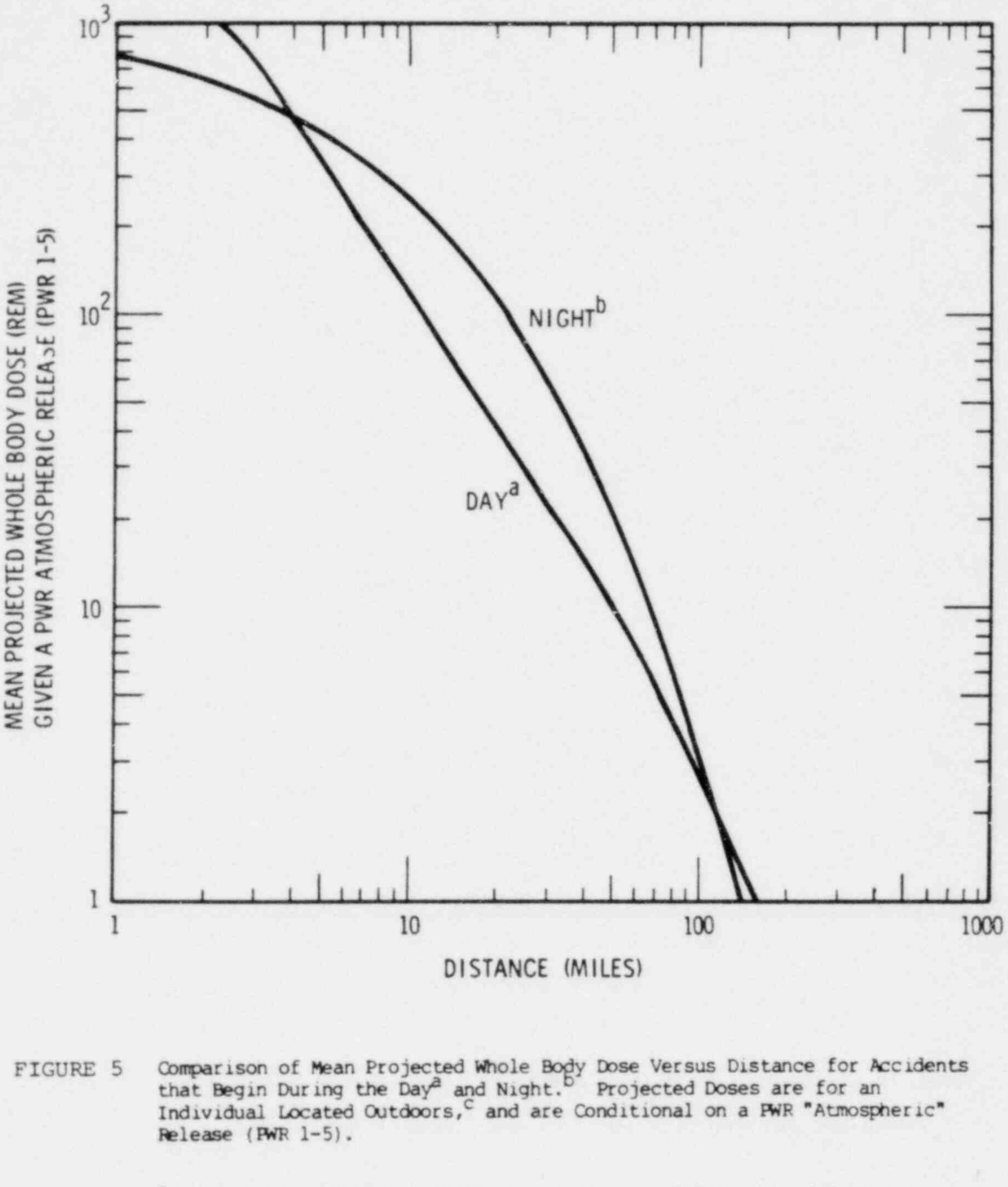


FIGURE 5 Comparison of Mean Projected Whole Body Dose Versus Distance for Accidents that Begin During the Day[a] and Night.[b] Projected Doses are for an Individual Located Outdoors,[c] and are Conditional on a PWR "Atmospheric" Release (PWR 1-5).

[a] Accidents in which the release starts between 7:00 a.m. and 7:00 p.m.

[b] Accidents in which the release starts between 7:00 p.m. and 7:00 a.m.

[c] Shielding factor for airborne radionuclides = 1.0. Shielding factor for radionuclides deposited on ground = 0.7. 1-day exposure to radionuclides on ground.

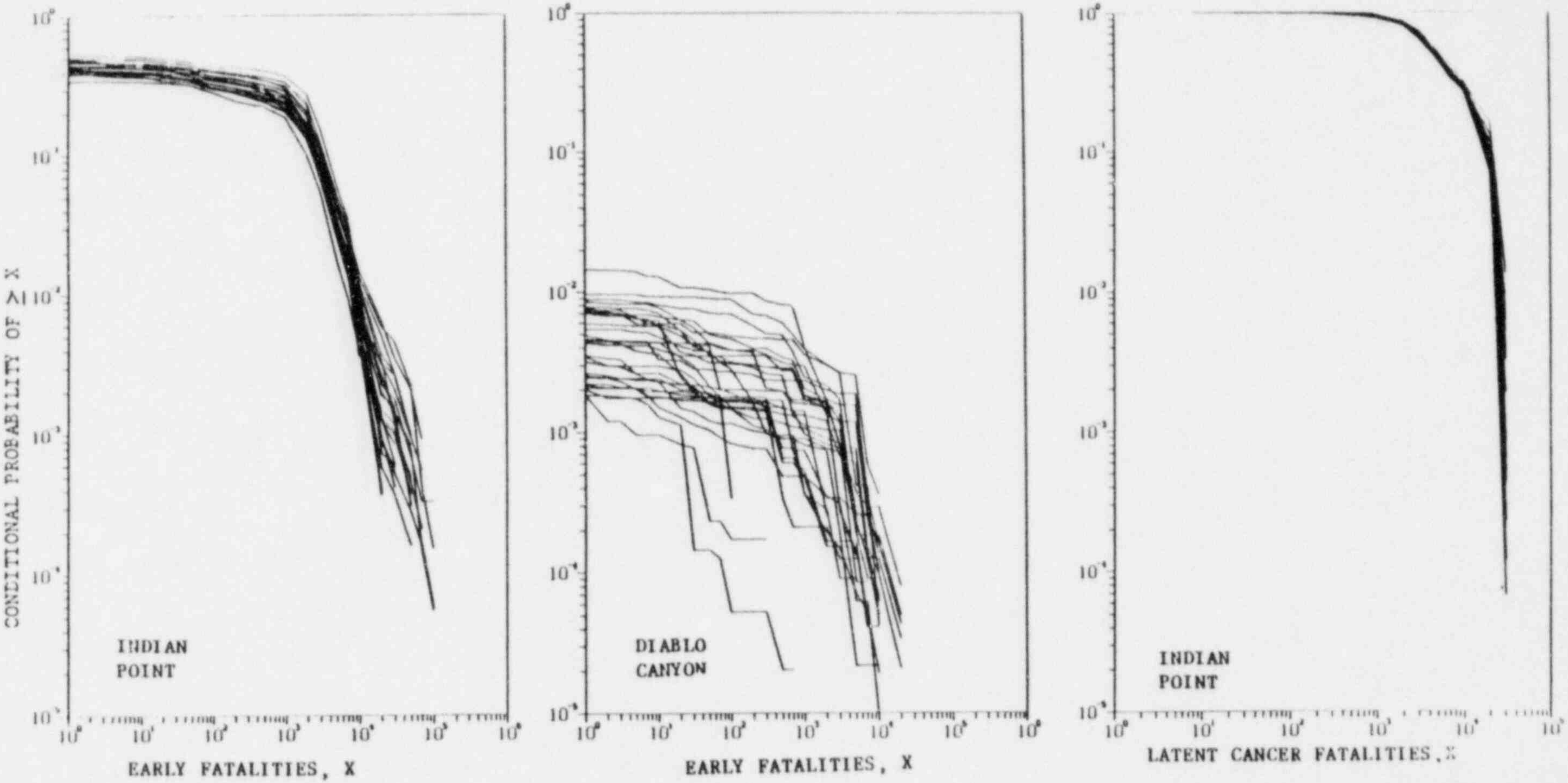
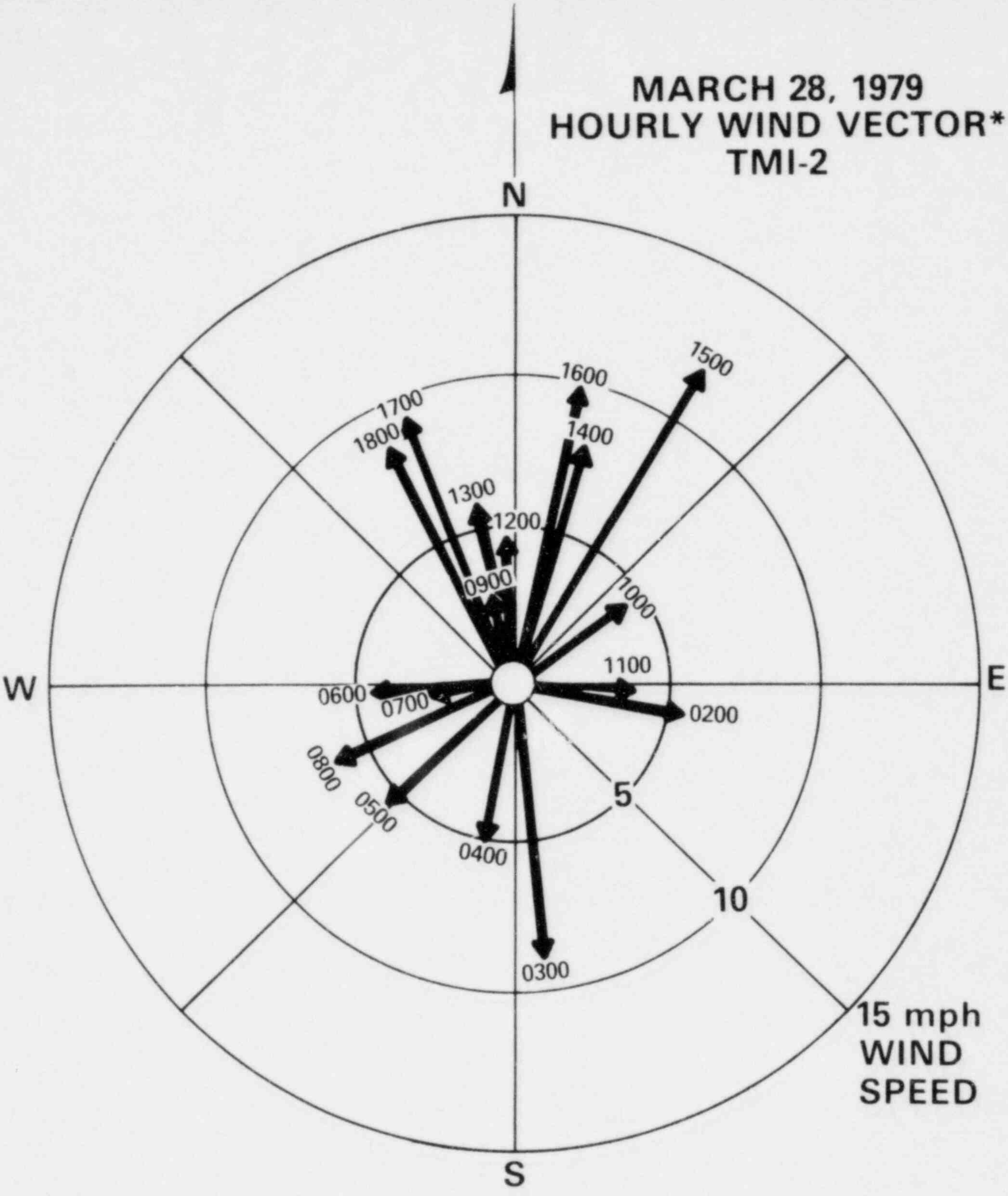


FIGURE 6 Probabilities of early and late fatalities for two sites, assuming: 1120 megawatt (electric) reactor, large release fractions, one hour warning before release, leisurely evacuation within ten miles. Meteorological data from 29 NWS weather tapes were used to generate the statistics, using 91 start times for the accident throughout a year, for each NWS type. Probabilities conditional on the accident occurring.



MARCH 28, 1979
HOURLY WIND VECTOR*
TMI-2

*Direction to which the on-site wind was blowing.

FIGURE 7

EMERGENCY ACTION LEVELS FOR LIGHT WATER REACTORS

A. E. Desrosiers
Pacific Northwest Laboratories*

WORKSHOP ON METEOROLOGICAL ASPECTS
OF EMERGENCY RESPONSE PLANS FOR
NUCLEAR POWER PLANTS

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*Operated for the Department of Energy by Battelle Memorial Institute.

An emergency action level (EAL) is an observation or judgment that forms the basis for declaring an emergency status at a nuclear generating facility. There are four graded emergency category classifications which indicate an increasing potential for offsite radiological impact. Each emergency category is normally associated with an implementation procedure that outlines the preplanned actions that the emergency director will undertake. Thus a transient which causes a system or parameter to reach an EAL will also cause a transition of the normal station organization to an emergency organization. This transition will include an augmentation of the basic shift staff in order to support the corrective and mitigative actions of the nuclear reactor operators. In this regard, the major purpose of EALs is to provide an early indication of potential problems. Ideally, the ensuing response of the emergency organization will prevent a propagation of errors or failures that could result in serious consequences.

Figure 1 shows an example set of EALs appropriate to a loss-of-coolant accident (LOCA) at a boiling water reactor (BWR). The EALs describe four parameters. Each parameter is individually adequate on which to base an emergency declaration. Note that these parameters describe the conditions of systems within the power plant.

Particularly, note that dosimetry calculations are not a prerequisite to declaring an emergency. Drywell area radiation level and drywell pressure could be input parameters to offsite calculations, however, requiring the operating staff to perform calculations prior to declaring an emergency would only detract from their primary role of corrective action and also would delay the emergency declaration. The declaration of a site emergency will mobilize both onsite and offsite emergency response organizations.

Figure 2 shows a generic EAL arrangement for a general emergency at a BWR. The EALs are arranged in groups which represent the status of the three primary fission product barriers. Again, dosimetry calculations need not precede the declaration of emergency status. Under these circumstances, the dosimetry calculations would be complicated by the need to estimate coolant and containment release fractions for halogens and volatile solids. Figure 3 gives recommended EALs for the same type of failure described in Figure 2, except that Figure 3 is referenced to a pressurized water reactor. The increased complexity of PWR systems is evident.

Figure 4 depicts EALs that are representative of a general emergency situation for a BWR, although the initiating condition is different from that in Figure 2. When large quantities of fission products are released to the containment, the dosimetry calculations must rely initially upon estimates of the containment leakage rate and the efficiency of standby filter systems.

In order to form a complete set of EALs, however, some consideration must be given to the case where offsite radiation doses occur via an unspecified fault in a reactor plant. Slide 5 shows the EPA's protective action guides (PAGs) for whole body exposure to radioactive plume. The PAGs for the thyroid gland are three times higher, except that there is not PAG for thyroid dose during lifesaving activities. These guides, or fractions of these guides, may be used as the basis of EALs that relate effluent or source term monitor readings to offsite projected doses.

This presentation discusses rapid dose assessment procedures that are in use today for performing initial dosimetry calculations. These calculations are for use directly as EALs or to provide initial dosimetry assessments to government agencies.

The calculations are sometimes performed using worksheets and calculators, dose rate isopleths, dose rate nomograms, dose projection nomograms, or small computers. Offsite or site boundary radiation measurements may confirm the calculations or cause revisions to the projections. However, measurements are generally too time consuming to be used as the basis for initial assessments.

Figure 6 shows a dose rate nomograph that includes the major considerations normally incorporated in rapid assessment methods. The dose assessment considers type of release (LOCA II, LOCA III), effluent monitor reading, vent flow rate and windspeed. The nomograph will give noble gas release rate and whole body dose rate at a distance of 1/3 mile. Stability class is considered implicitly.

For sites with complex terrain where dispersion has been measured, overlays of isopleths may be more accurate. However, the major purpose of an initial assessment is to approximate the potential maximum offsite dose to provide an initial point of reference for local government response and monitoring teams.

The whole body dose should not include contributions from beta particles as these doses are generally superficial and easily shielded by shelters such as automobiles and residences.

Figure 7 demonstrates that dose calculations based upon the assumption that the released radioactivity is exclusively Xe-122 will significantly underestimate the dose if the release consists of a mixture of radioactive noble gases. In Figure 7, the mixture of noble gases in the core at end-of-life (WASH-1400) is used for comparison. The assumption that the release is exclusively Xe-125 is reasonably accurate during the first 8 hours after reactor shutdown.

The radiological analyst should be aware that a detector calibrated for Xe-133 may not accurately respond to a mixture of noble gases or other noble gas release.

Figure 8 shows, for the case of iodine, that the assumption of a mixture of iodines in the release gives a lower dose rate than the case where only I-131 is assumed to be released.

To summarize, rapid dose assessment systems have been largely replaced by plant system parameters in preparing EALs. Rapid dose assessment systems, however, have a definite role.

The accuracy of these initial calculations of projected dose is limited by knowledge of the source term and its rate of change over time as well as uncertainty regarding the exact radionuclide composition of a rapid release. A major upgrading of assessment capability occurs as soon as the technical support center and emergency operations facility are staffed.

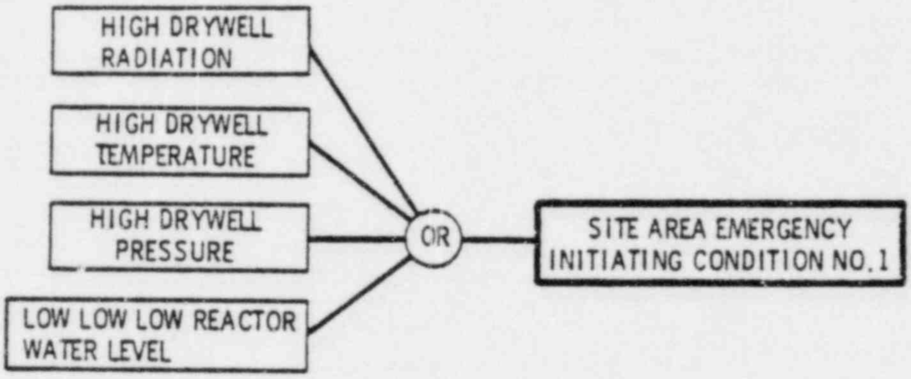


Figure 1 - Recommended Generic EALs for a LOCA (BWR)

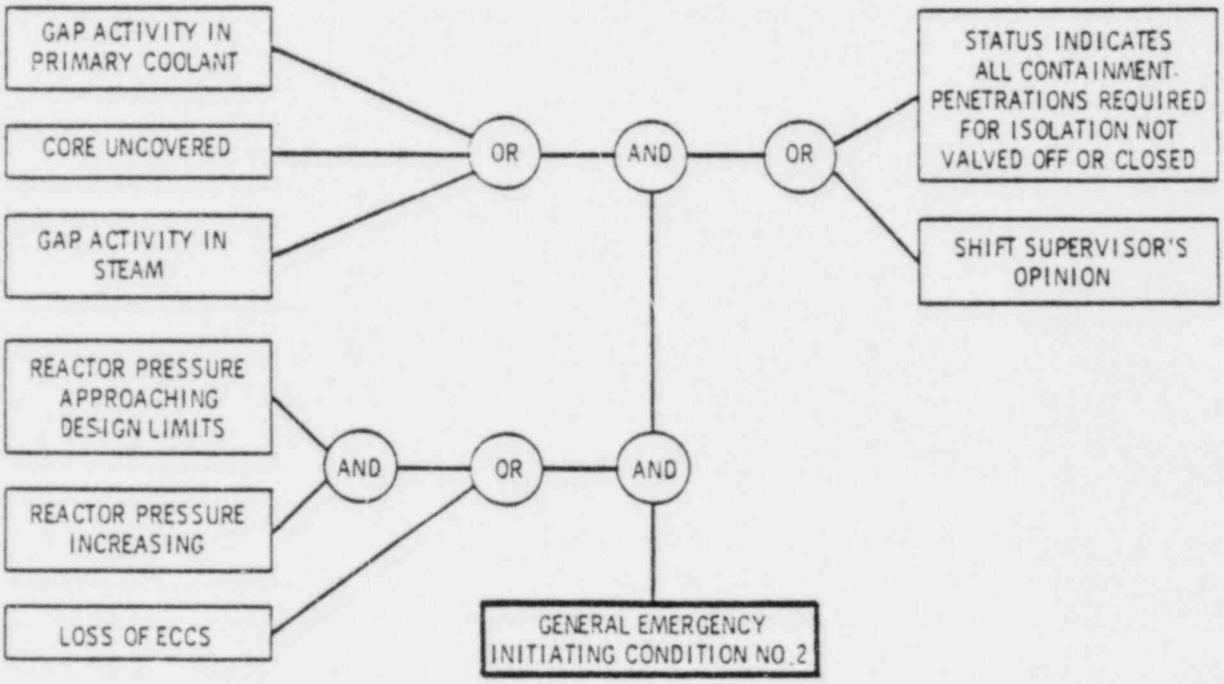


Figure 2 - Recommended EALs for Failure of Cladding and Containment with Potential Loss of Primary Coolant Boundary (BWR)

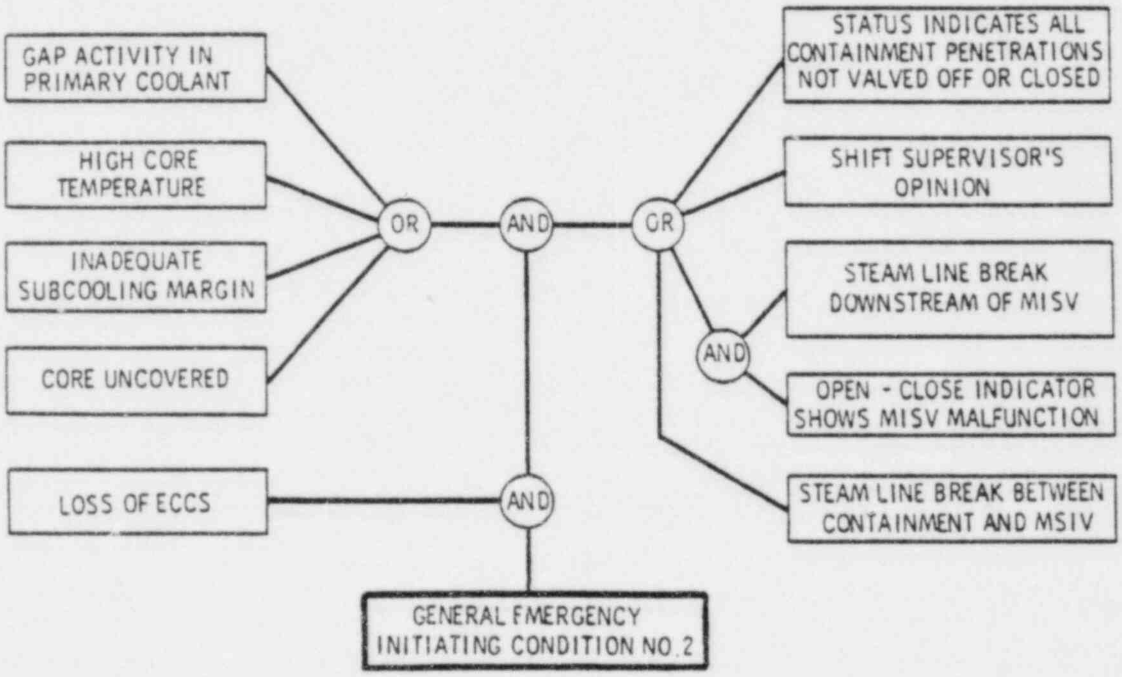


Figure 3 - Recommended EALs for Failure of Cladding and Containment with Potential Loss of Primary Coolant Boundary (PWR)

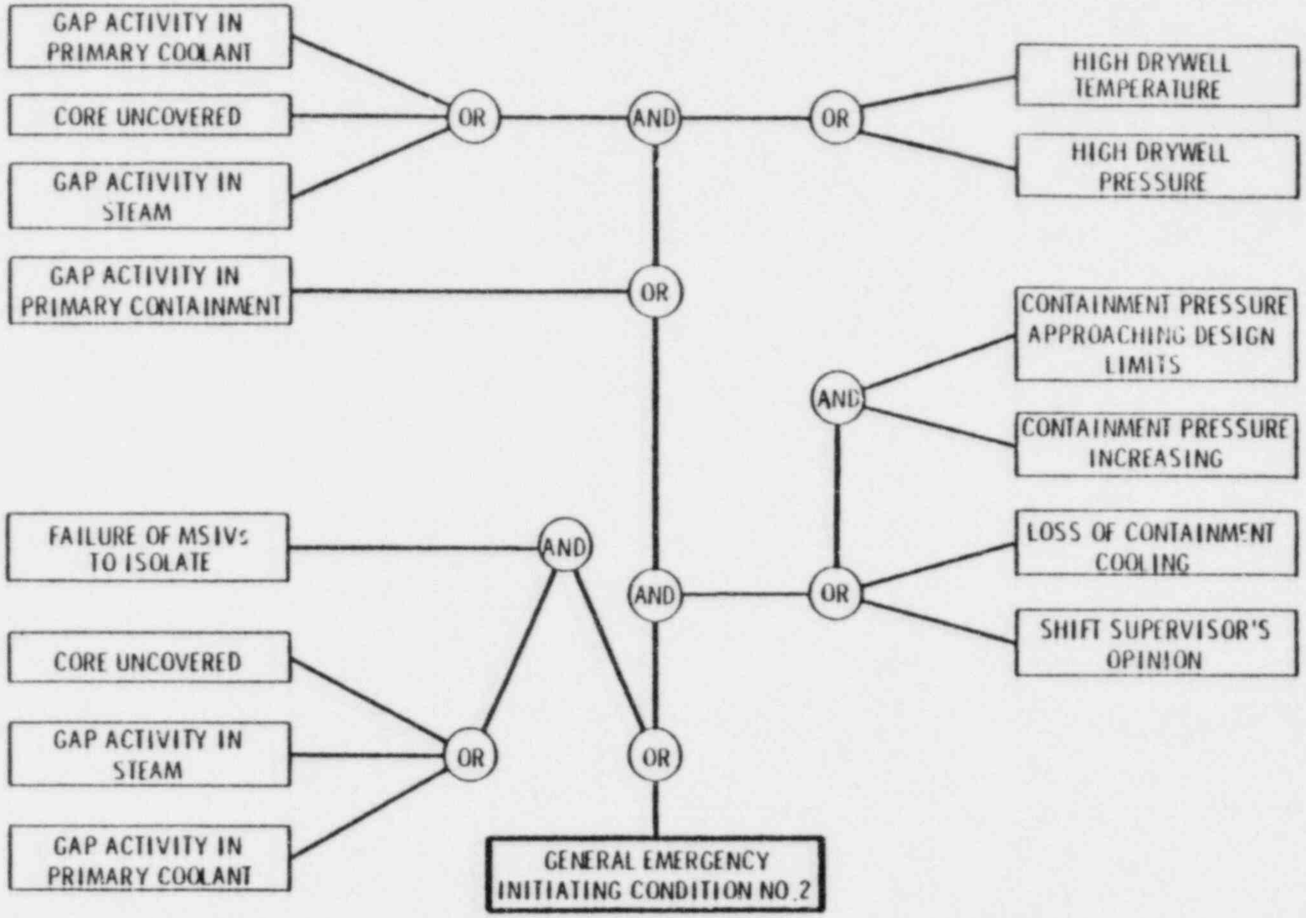


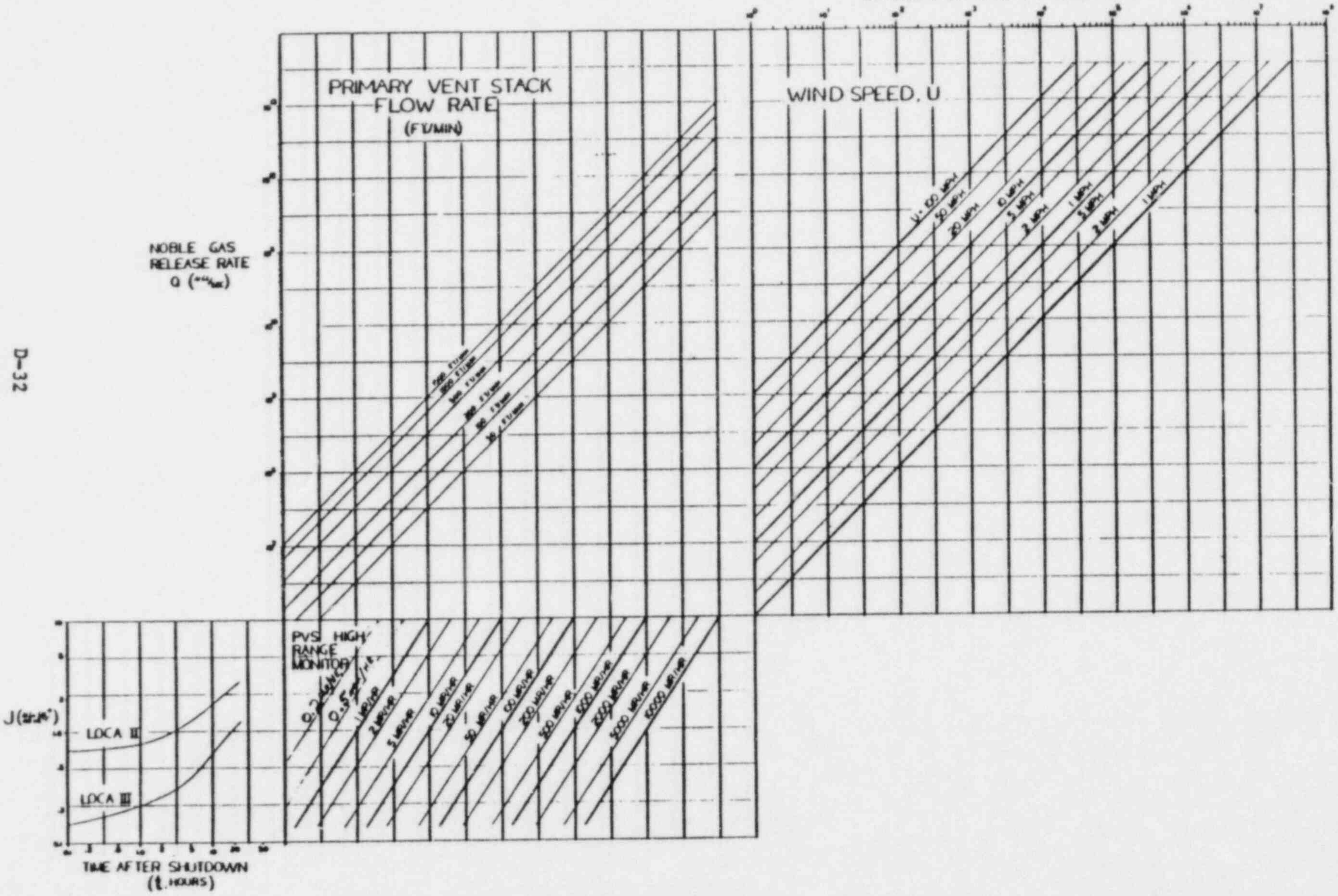
Figure 4 - Recommended EALs for Failure of Cladding and Primary Coolant Boundary with Potential Loss of Containment (BWR)

Slide 5 - PROTECTIVE ACTION GUIDES FOR WHOLE BODY EXPOSURE TO AIRBORNE RADIOACTIVE MATERIALS

Population at Risk	Projected Whole Body Gamma Dose (Rem)
General population	1 to 5(A)
Emergency workers	25
Lifesaving	75

(A) When ranges are shown, the lowest value should be used if there are not major local constraints in providing protection at that level, especially to sensitive populations. Local constraints may make lower values impractical to use, but in no case should the higher value be exceeded in determining the need for protective action.

Figure 6 - EMERGENCY OFFSITE DOSE NOMOGRAM



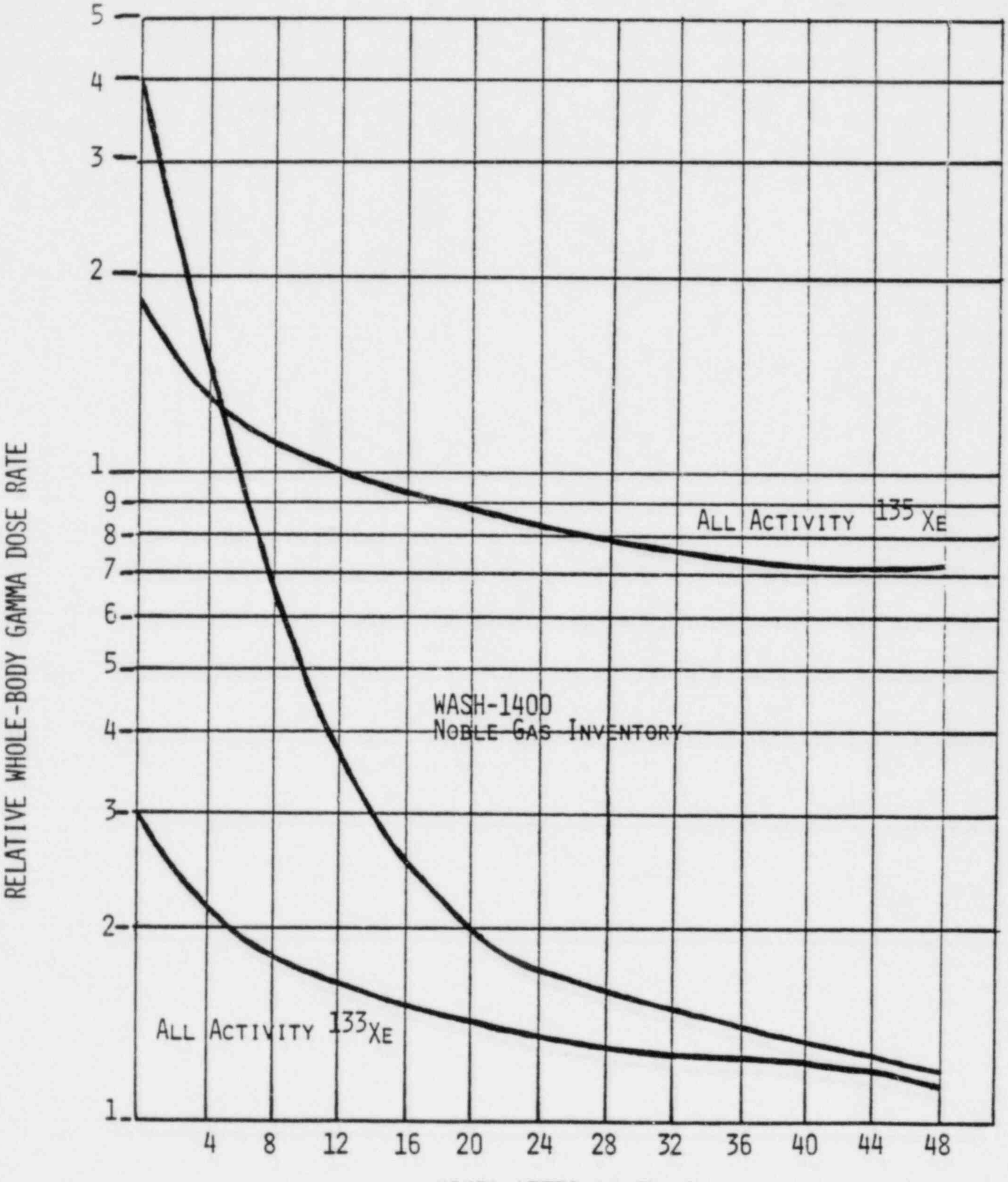


FIGURE 7 - RELATIVE WHOLE-BODY DOSE RATE FROM NOBLE GASES VERSUS TIME AFTER REACTOR SHUTDOWN

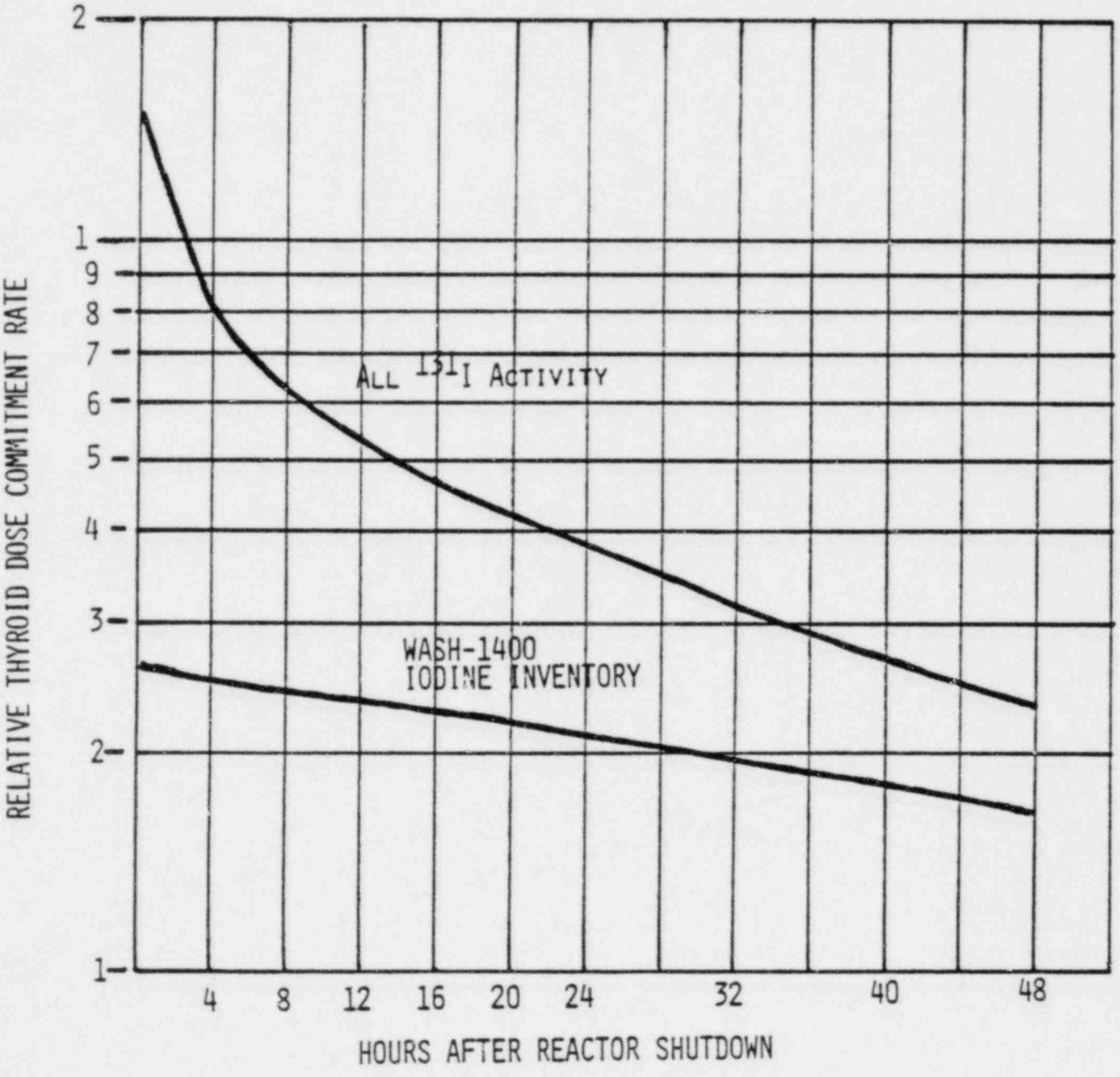


FIGURE 8 - RELATIVE THYROID DOSE COMMITMENT RATE VERSUS TIME AFTER REACTOR SHUTDOWN

EMERGENCY RESPONSE FACILITIES

Steve Ramos
U. S. Nuclear Regulatory Commission

Studies performed both within and outside the Nuclear Regulatory Commission (NRC), as a result of the TMI accident, have identified the need for extensive improvements in the facilities and systems to manage and mitigate accidents at nuclear power plants. The emergency facilities needed for management of a nuclear accident are the reactor control room (CR), the Technical Support Center (TSC), the Operations Support Center (OSC), and the nearsite Emergency Operations Facility (EOF). The CR provides for the operation and manipulations of the reactor controls and instrumentation. The TSC is an onsite facility located near the CR to provide plant management and technical support to the reactor operating personnel during an emergency. The OSC is an onsite assembly area, away from the CR, where operations and technical support personnel will report in the event of an accident. The EOF is a nearsite support facility for overall management of the emergency response including the coordination with offsite officials.

The additions to the plant data system are the Safety Parameter Display System (SPDS) and the Nuclear Data Link (NDL). These systems are provided information by a common data base. The SPDS is displays of plant parameters used to assess the safety status of plant operations in the CR. The NDL is a data transmission system to provide a set of plant data to the NRC Operations Center. The plant data system changes include improvements in the inplant monitoring and measuring systems, meteorological measurements and offsite dose projection from accidental releases of radioactivity. All of these improved or additional facilities and systems are described, including their general hardware and software, instrumentation and structural features.

INTERFACE BETWEEN HEALTH PHYSICS AND METEOROLOGY

(N. R. HORTON)

The subject for this session of our workshop is entitled, "Interface Between Health Physics and Meteorology."

I imagine that most of us here today have a reasonable understanding of the calculations which are required to translate a core fission product source term to potential health effects. What we may not appreciate is the potentially enormous variability in these potential consequences due to such features as site meteorology, effective release height, terrain features, land cover, precipitation, effectiveness of engineered safety features, capability to evacuate offsite population if needed, etc. As such, two reactors producing 1000 MWe each,manufactured by different vendors, constructed by different AEs and located on different sites will in reality produce significantly different radiological consequences. The licensing world, which most of us have been associated with, does not correctly treat these differences. As a consequence, the conservatively evaluated potential consequences may not be able to distinguish between these two plants, however, Mother Nature, as evidenced by TMI, correctly brings into proper focus the errors of such conservatism.

I believe that the interface between Health Physics and Meteorology is very well defined and easy to understand. However, I do not believe that, in general, we have progressed in our understanding and in the mathematical treatment of atmospheric dispersion to the same degree that our understanding of potential health related affects from exposure to radioactive materials has progressed. If I am correctly interpretating the requirements in NUREG 0654, it appears that the site specific class A and Class B models have the potential for correcting the deficiency in this area.

NUREG 0654 states "The most important guidance in the report for planning officials is the definition of the area over which planning for predetermined activities should be carried out." I would interpret the predetermined activities of primary concern to be the need for evacuation or sheltering if required and the restriction of contaminated water intake. Diverting the use of or reducing the consumption of agricultural products or land interdiction will be a second order concern and can be arrived at by physical measurements which are based on predicted areas of contamination. To develop the most effective plan relative to the need to evacuate people it is, in my opinion, an absolute requirement that meteorological modelling, fission product release to the environment, and atmospheric transport and deposition be evaluated in as realistic of a manner as possible. The conservative Licensing models are not satisfactory for this application. If our release/diffusion/dose modelling results in conservative overestimates needless evacuation, needless emotional trauma and potentially needless deaths as a consequence of evacuation will occur. However, on the opposite side of the coin, under estimates of the potential consequences may in reality result in over exposure and potentially serious biological effects. Therefore, we are in a position that being on either side of the correct answer is potentially unacceptable and may lead to the wrong course of action.

I want you to understand that I am not naive enough to believe that we can correctly model all of the complex interrelationships of the parameters that I have previously mentioned, however, I know we can develop more representative models than we have in the past, particularily in meteorological modelling where we have a daily test program to perfect our modelling capability.

As I reflect on the past 20 years of being involved in radiological modelling and dose predictions, I can see major improvements in our capability to predict radiological consequences. My first exposure to such evaluations occurred on the LOFT and SNAP-TRAN programs in Idaho, where we used cummulative fission yields to hand calculate equilibrium core inventories, Sutton's diffusion equations for atmospheric transport and slide rules for mathematical calculations. Well we have come a long ways, in some areas, since those days; today we have 8 places of computerized accuracy, improved process and meteorological measurement equipment and micro processors to digest all of the input and publish it in a form we can send directly to the NRC. As an industry, we have spent billions of dollars in test programs directed at better understanding complex physical phenomena and in designing and installation of engineered safeguards which will mitigate the consequences of accidents if they do occur.

The reason we are here this week is to provide input into the practical implementation of NUREG 0654 and hence to provide another layer of protection for individuals located in the vicinity of a nuclear power plant.

As a private citizen of this great country, I find in my own mind an unreconcileable paradox that on one hand we spend billions of dollars for the protection of the public in the design and installation of engineered safeguards to mitigate the consequences of events which have a probability of occurring of once in ten thousand years to once in a million years while on the other hand we subsidize the growing of a product, namely tobacco, which has been shown with a probability of 1 of killing thousands of individuals in this country every year. I also noted in our local newspaper this week that drunk drivers killed 28,000 people in the U.S. last year. At that rate, that is 1/4 of a million people in 10 years. And again the probability is 1 not 10^{-4} to 10^{-6}. What is the worth of one life - Evidently, not too much when it comes to alcohol or tobacco.

Personally, I for one am extremely proud of the fantastic safety record we have achieved in the nuclear industry. I am not an enthusiastic supporter of government regulations, however, I feel that we can attribute part of this impressive safety record to the regulations we are forced to comply with. I see NUREG 0654 as being overall a worthwhile document to implement. It is up to us these next few days to provide those recommendations which will result in the most effective implementation of the guidance set forth in this document.

To aid us in arriving at these recommendations we have three topics which will be addressed for the remainder of this session of our workshop. The first topic "Meteorological Aspects of Particular Importance to Health Physicists" will be given by Mr. Malcolm Pendergast of the Savannah River Laboratory. The second topic "Current Plume Model Methods" by Mr. Walter Pasciak of the Nuclear Reactor Regulation Branch of the NRC and the third topic "Surveillance Methods and Associated Uncertainties" by Mr. Eugene Bates of the Inspection and Enforcement branch of the NRC.

DP-MS-82-3

ASPECTS OF METEOROLOGY OF IMPORTANCE TO HEALTH PHYSICISTS

by

Malcolm M. Pendergast

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A paper proposed for publication in the Proceedings of the
Nuclear Regulatory Commission Workshop
Menlo Park, California
December 1 through December 3, 1981

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ASPECTS OF METEOROLOGY OF IMPORTANCE TO HEALTH PHYSICISTS

by

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For the health physicist, just like many other people, often the weather is either good or bad. But immediately following an accident, the health physicist on duty at a nuclear facility will make many important decisions based upon his understanding of the weather conditions during and following the accident.

Today I am going to summarize what I feel are the important aspects of meteorology of concern to the health physicist on shift. These ideas are based upon my experiences working with the meteorologists and health physicists at the Department of Energy's Savannah River Plant.

Since construction of the SRP in 1952, many improvements have been made in the site emergency response system. The present system boasts a network of meteorological towers and monitoring stations, and a computerized system capable of assessing consequences of an accident with literally the touch of a single button. The strength of this system is that it was developed by meteorologists for the health physicist on shift. It has evolved over the last seven years as the result of continued interactions between health physicists and meteorologists. The system is constantly being improved. Improvement has resulted from 1) frequent practice exercises, 2) tracer releases, and 3) activating the emergency response system for minor releases.

Before I summarize the meteorological aspects, I would like to briefly list those tasks performed by the Health Physicists which

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* The information contained in this article was developed during the course of work under Contract No. DE-AC09-76SR00001 with the U.S. Department of Energy.

require either direct or indirect meteorological information. These tasks are:

1) Minimize dose-to-man from accidents

2) Monitor to assess dose-to-man

3) Optimize cleanup

4) Minimize routine dose.

For accidents when radioactivity is released to the environment, meteorology can be very important. In fact, the success that the health physicist has in performing his tasks is related to the degree to which meteorological information is utilized.

Once the magnitude of the release has been established, the severity of the dose effect must be ascertained. This will determine the actions taken. This determination is greatly affected by wind direction and atmospheric stability.

One of the most important aspects of any incident is the ability to quantify, with confidence, the dose-to-man of the accident. The monitoring program is very important, as actual data are often preferred to calculations by many people (such as governors, senators, etc.). Meteorological data are required to direct where the sampling is to be carried out as well as what to look for. For example, if it was raining during the accident the sampling for tritium oxide would be centered on water samples rather than vegetation. The same goes for cleanup. It is necessary to know what to clean up and where it is.

The probability of a nuclear accident is low. In some instances the probability can be even lower if meteorological data are used as input for the scheduling of work. For example, transfer of some radioactive material between areas at the SRP is suspended during rainstorms. Traces of contamination on shipping casks could be washed off and spread onto the ground. Another example at SRP is that strong winds could strip away protective plastic covering placed on mining probes used in waste tank operations and contaminate larger areas. For these reasons forecasts of rainstorms and wind speeds are monitored and used during the operation. An added benefit of using meteorological information during routine operations is that it enhances the line of communication among health physicists and meteorologists and in effect provides training for an emergency.

With respect to meteorological aspects during an accident, the health physicist should know how to obtain the basic meteorological data. Once the data are obtained, the calculations can be performed.

At this time it will be sufficient to say that calculations will be performed using either a computer, calculator, slide rule, or a simple nomogram.

The culmination of all preplanning, data gathering, and hard work is in presenting the results to the appropriate agency so that action can be taken. This is the most important step of all. The results should be presented in a manner so that misinterpretation is minimized. Generally, simple maps showing areas affected and key features are preferred.

Figure 1 is an example. This depicts ground level air concentrations resulting from a hypothetical 60 pound per minute leak of hydrogen sulfide from the SRP heavy water production facilities. Note the roads, river, railroads, and plume isopleths are indicated. Note all units are those used by the health physicist on a routine basis.

A full understanding of the effect of meteorology on releases is a goal shared by all air pollution meteorologists. This should not be expected of the health physicist who has many other tasks to take care of during an accident. There are several variables, however, with which he should be reasonably familiar. These are wind direction and speed, atmospheric stability, and the existence of significant weather.

If the health physicist can answer the following questions, I say he is familiar with the variable.

1) Where can the information be obtained?

2) Where can backup information be obtained? How applicable?

3) What importance does it have to dose-to-man?

For Example:

Wind direction and speed are generally available from onsite towers, and backup data usually come from a secondary tower or the nearest National Weather Service station. If the backup observation is at a different height above the ground, the expected difference in speeds at the two heights should be known. For example, during very stable conditions at SRP, speeds increase by about 250% from 10 to 100 m. The amount of increase is dependent upon stability and site terrain characteristics. Immediately following an accident, knowledge of the wind direction and speed can be used to minimize dose by evacuating personnel or keeping people from driving into the path of the plume via automobile, boat, train, and airplane. Here is where good communications are required. Depending upon the site, the strength of the wind speed can have either an adverse or positive effect on the dose from the release. A knowledge of unique problems is important, such as a critical wind direction to a population center.

Atmospheric stability is a derived quantity which can be obtained from a number of sources such as vertical temperature gradient, wind variability, and weather conditions. Stability is extremely important in estimating the air concentration and dose at any downwind distance. For a certain release rate and travel distance, the air concentration can range by several orders of magnitude depending upon atmospheric stability. My point is that the health physicist should know that it is important.

At the SRP the primary source of stability is the standard deviation of wind direction. If an instrument fails, there are seven towers as backup. If the computer fails, data can be extracted from stripchart records. Our health physicists are trained to use the bandwidth, which is the maximum swing of the wind direction over the past 15 minutes. This is related to the standard deviation of wind azimuth. Incidentally, our nomograms use source strength, wind speed, and bandwidth as input. The final backup is information from the nearest airport on cloud cover and wind speed using the Pasquill stability classification.

Weather information can be obtained from looking out the window, the nearest NWS station, or from TV or radio. Forecasts are generally available from the same sources. At the SRP we have automated wind and stability forecasts as part of our emergency response system. The SRP is the only site to have automated 30-hr forecasts at all times.

The effect of rainfall on each release scenario should be known in advance as it affects both the dose pathway as well as monitoring operations. I mentioned the effect of weather during routine operations. Weather information is also used during cleanup operations. For radionuclides being transported as particulates, such as ruthenium, a final protective measure to minimize dose-to-man is to plow the soil under. Plowing during a dry windy day would make matters worse.

Many non-meteorological variables are important in the accident assessment. Just like the meteorological variables, a full understanding of their effect on dose calculations is our goal. The three most important are height of release, building wakes, and terrain influences.

The effect of some variables such as height of release are known better than others, such as terrain and building wakes. The health physicist should know the expected release heights for all possible accident scenarios and know how dose is related to release height. In addition, the effect of a building wake on initial dilution and particularly its effects on air intake vents of adjacent buildings should be known and accounted for when required. Finally the existence of significant local terrain should be known. Often pronounced terrain effects such as mountain-valley winds and channeling of the wind become apparent as the result of a brief study of the local climatology of the site wind.

I have listed a few aspects of meteorology of importance to the health physicist. As I have presented it, meteorology is important in many phases of an accident ranging from dose calculations, to monitoring, to cleanup. The health physicist on shift should have a basic understanding of what meteorological aspects are important for the task he is performing. This man will have a lot of things on his mind during the initial phase of an accident. He should not be expected to retain information considered superfluous to the task at hand.

DATE: 11/25/81 TIME: 3:59:59 PM EST
15 MINUTE-AVERAGED WIND FROM 199.DEG AT 4.7MPH
BAND WIDTH IS 129.DEG, SIGEL IS 16.DEG

D AREA

H2S SOURCE
60.000 LBS/MIN

ISOPLETHS (PPM)

————	1.0E+00
- - - - - -	1.0E-01
—— - ——	1.0E-02
— — —	1.0E-03

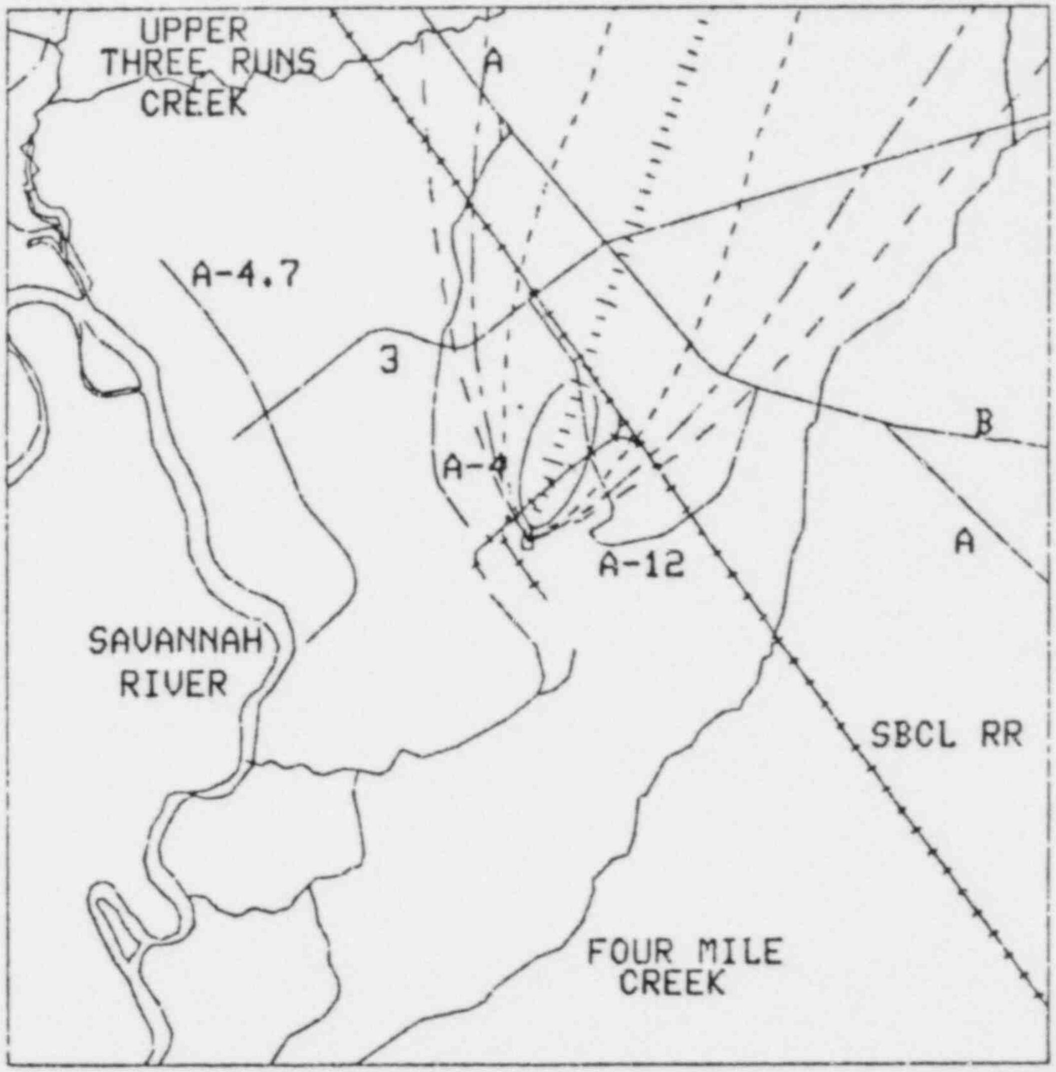

FIGURE 1

NRC MODEL FOR CALCULATION
OF DOSES FOR EMERGENCY RESPONSE

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Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

The NRC Radiological Assessment Branch Staff has developed a computer code for the purposes of evaluating dose for emergency response. The code is called RADPUR, is written in Fortran IV computer language, and operates in an interactive fashion. The code employs finite and semi-infinite modeling approaches for selected locations downwind of the source, and is based upon Gaussian, straight-line atmospheric modeling techniques. It provides meteorological dispersion parameters that take into consideration stack elevation, plume rise, building wake, and receptor distance and elevation. The meteorological input parameters are wind speed, stability class, and wind direction. The radiological input parameters consist of a nuclide specific source term for each period of constant meteorological conditions.

The doses are calculated for both the sector average concentration (16 sector system) and the plume centerline concentration. For both the sector average and centerline concentrations, the code calculates doses based upon both the semi-infinite model and finite model. The dose calculations may be made for as many as twenty different noble gas radionuclides.

The semi-infinite modeling technique employed in the code is similar to that used in the development of the MPC values of ICRP-2 and the same as that described in NRC Regulatory Guide 1.109. This approach is based upon the assumption that the noble gas cloud is infinite in all directions above the ground plane. In reality, clouds do not extend to infinity, thus, this approach generally results in overestimates of actual doses. The conservatism of this approach has historically been considered appropriate for regulatory purposes. The finite model employed by the RADPUR code is based upon the assumption that the cloud is infinite in the horizontal plane, but finite in the vertical direction. This approach was selected as it most closely resembles the three-dimensional infinite approach, as it is infinite in two dimensions, while at the same time provides a more realistic treatment of elevated clouds.

For the purpose of emergency response it may be useful to have available more complex meteorological modeling techniques such as puff release models or variable trajectory models, however, it may not be useful to factor results of these models directly into the dose calculational models. This is because of the fairly simplistic approach used in most of the dose calculational routines. The purpose of having the more complicated meteorological routines available would be to better estimate the location of the plume, and where to apply the results of dose calculations based on the straight-line model.

The dose-integral routines of the finite portion of the RADPUR code are based upon a nine-group energy method, rather than on an average energy, nuclide specific method. This nine-group method provides more accurate respresentation of the actual photon energy distributions of each of the 20 nuclides.

The RADPUR code requires little training to operate. Once logged onto the system, the computer informs the user in a step-wise manner the information necessary to run the code. Certain basic information for nuclear power reactors are stored in the files associated with the code. This information includes elevation and distance in each sector to the exclusion boundary, size of plant buildings, and effluent release point characteristics. The user may elect to input this information for non-standard facilities. Figure 1 depects an example printout of dose calculations made by the code. The user may select either doses calculated on the basis of sector average concentration or centerline concentration, and for each of the two dose models. Also, doses are presented for gamma air, beta air, total-body, and skin.

The code will eventually be published for public use, but before this is done a few additions will be made. The most important of these will be the inclusion of routines for handling particulate transport and desposition so that doses can be calculated for inhalation of particulates and for external exposure due to ground deposition of particulates.

In order to avoid the need of running the RADPUR code to estimate doses from finite elevated clouds, the staff has prepared nomographs that allow the doses from these clouds to be read directly. While running the code with all the input parameters defined for the specific problem is desirable, the nomographs allow the estimates to be made by hand (certain factors are not taken into consideration in the band calculation such as building wake and plume rise). Figure 2 depicts a sample nomograph. The dose per curie released can be read by drawing a straight line between the appropriate points on each half of the nomograph. An example calculation is depicted on Figure 2 for a distance of 1000 m, a wind speed of 0.5 m/s, and G class stability. The point at which the straight line crosses the center ordinate is the dose per curie.

These nomographs will be published for public use in the near future. Included in this nomograph publication will be regression equations that will allow the user to calculate doses out to distances as great as 5 miles. These regression equations will allow calculations of doses from finite clouds by means of hand calculators for the release elevations of 100 m and ground level.

The results of the RADPUR code have been compared with finite methods presented in two other publications. These are (1) "Assessment of Gamma-Ray Exposures Due to Finite Plumes", by Lahti, Hubner, and Golden, and the (2) "Concentric cylinder set model for estimating dose from gamma-emitting cloud, by John Arras. The results of the RADPUR code agreed well with the results of these models.

1. Lahti, G.P., R.S. Hubner, J.C. Golden, "Assessment of Gamma-Ray Exposures Due to Finite Plumes," Health Physics, Vol. 41, pp. 319-340, 1981.
2. Arras, J.M., "Concentric cyliner set model for estimating dose from gamma-emitting cloud", AFRRI Technical Report, Report No. TN81-1, March 1981.

```
-----------------------------------------------------------------------
      DOSE ESTIMATES BASED ON SECTOR AVERAGE CONCENTRATION
-----------------------------------------------------------------------
            FINITE PLUME DOSES         INFINITE PLUME DOSES
         -------------------------- -------------------------------
          AIR    TOTAL                AIR     AIR    TOTAL
 SECTOR/ GAMMA    BODY    SKIN       GAMMA    BETA    BODY    SKIN
DIST(M)  (MRAD)  (MREM)   (MREM)    (MRAD)  (MRAD)  (MREM)   (MREM)
-----------------------------------------------------------------------
NNE      .24E+01 .21E+01 .58E+01 .66E+01 .79E+01 .60E+01 .10E+02
S        .66E+00 .61E+00 .12E+01 .10E+01 .99E+00 .97E+00 .16E+01
-----------------------------------------------------------------------
-----------------------------------------------------------------------
     DOSE ESTIMATES BASED ON CENTERLINE CONCENTRATION
-----------------------------------------------------------------------
            FINITE PLUME DOSES         INFINITE PLUME DOSES
         -------------------------- -------------------------------
          AIR    TOTAL                AIR     AIR    TOTAL
 SECTOR/ GAMMA    BODY    SKIN       GAMMA    BETA    BODY    SKIN
DIST(M)  (MRAD)  (MREM)   (MREM)    (MRAD)  (MRAD)  (MREM)   (MREM)
-----------------------------------------------------------------------
NNE      .75E+01 .66E+01 .18E+02 .21E+02 .25E+02 .19E+02 .33E+02
S        .10E+01 .93E+00 .18E+01 .16E+01 .15E+01 .15E+01 .25E+01
-----------------------------------------------------------------------
```

FIGURE 1

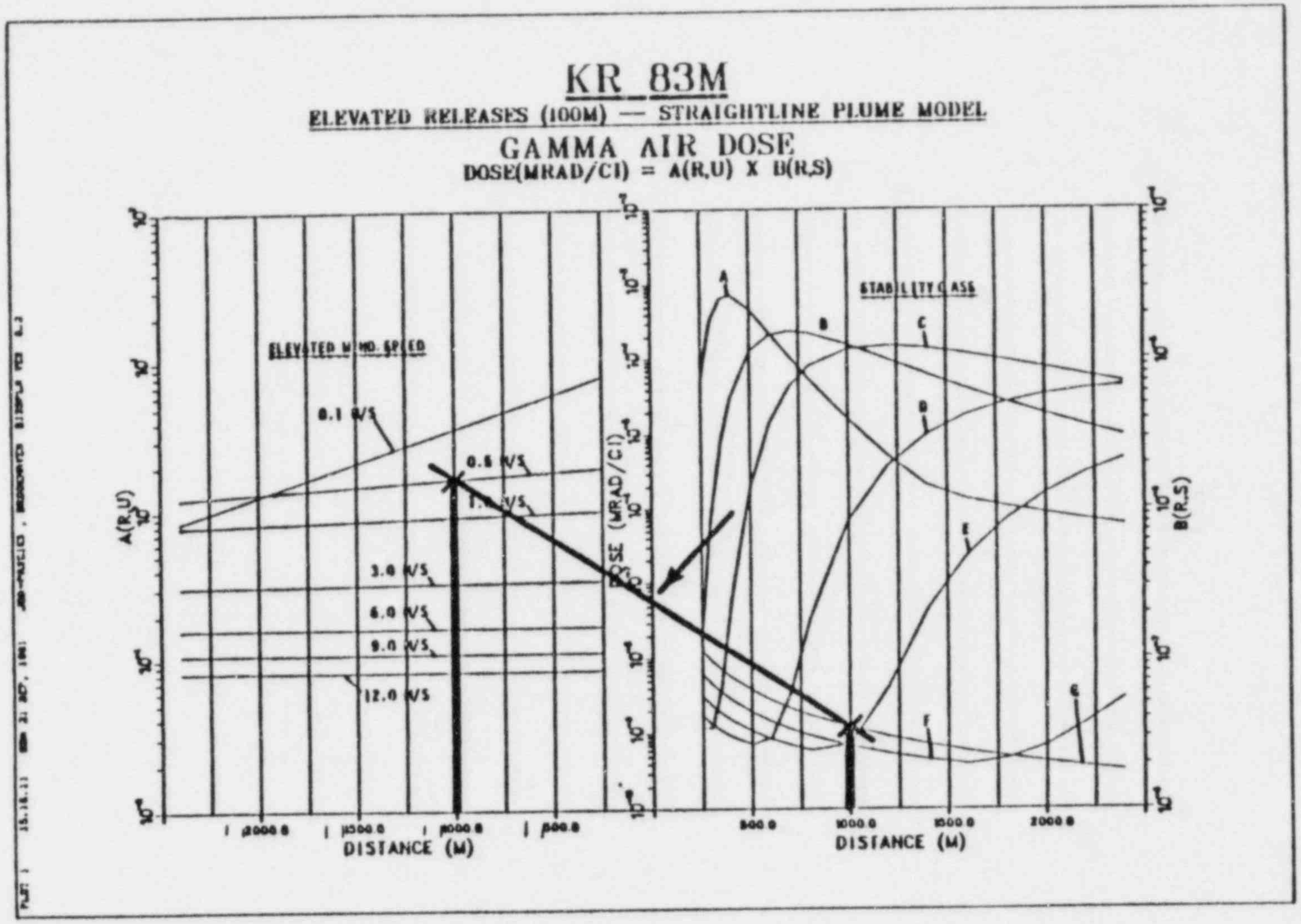
KR 83M
ELEVATED RELEASES (100M) — STRAIGHTLINE PLUME MODEL
GAMMA AIR DOSE
DOSE(MRAD/CI) = A(R,U) X B(R,S)
ELEVATED WIND SPEED
0.1 M/S
0.5 M/S
1.0 M/S
3.0 M/S
6.0 M/S
9.0 M/S
12.0 M/S
A(R,U)
DOSE (MRAD/CI)
STABILITY CLASS
A
B
C
D
E
F
G
B(R,S)
2000.0
1500.0
1000.0
500.0
DISTANCE (M)
500.0
1000.0
1500.0
2000.0
DISTANCE (M)

FIGURE 2

"INTERFACE BETWEEN HEALTH PHYSICS AND METEOROLOGY"

SURVEILLANCE METHODS
AND
ASSOCIATED UNCERTAINTIES

GENE BATES
DIVISION OF EMERGENCY PREPAREDNESS
OFFICE OF INSPECTION AND ENFORCEMENT
U.S. NUCLEAR REGULATORY COMMISSION

SUMMARY

The methods and techniques used to determine the need to implement offsite protective actions have a profound effect on the decisionmaking process. The translation of an atmospheric release of radionuclides to potential health effects is based primarily on two systems. One system is an initial dose projection method using real-time meteorological data and the source term with associated release rates. The other system is that of verification and supplement to the initial dose projection system. This system is based on in-situ monitoring of the offsite environs. This paper addresses the latter of these systems.

The offsite monitoring system consists of three measurement methods used in cloud tracking (plume movement and location) and the delineation of the extent and magnitude of the release of radionuclides to the environs. The monitoring methods are (1) fixed monitoring stations, (2) aerial monitoring, and (3) mobile (ground) survey teams.

The fixed monitoring stations method requires the deployment of a large number of detectors for radioiodine and direct gamma measurements and the telemetry network necessary for such a system to provide the required information for verification and/or modification of the initial dose projection. This method of estimating the plume dispersal and projecting dose patterns has one major problem. That is, the initial cost, required calibrations, and maintenance of the measurement system is very high and in most cases cost prohibitive. This method is also limited in its scope to provide data for extended distances from the point of release.

The aerial monitoring method has its limitations because ground level exposure rates cannot be determined from measurements made above the plume. However, aerial monitoring can provide useful information for the ground level survey teams in determining the direction of plume movements, and to some degree, the extent and magnitude of the plume. Uncertainties associated with aerial measurements can result from aircraft contamination; thus, erroneous plume movement data could be factored into the decisionmaking process when evaluating offsite consequences.

The mobile (ground) survey method provides measured radiological data that can be used to verify or modify the initial dose projections. The mobile ground survey team plays an important role in the analysis and evaluation of the movement and magnitude of released materials.

The major problem associated with ground survey team data is the lack of an acceptable quality assurance program for making field measurements. Additional problems included the lack of area maps with defined landmarks, insufficient number of teams, communications, logistics of equipment, and measurement techniques for direct radiation and air sampling.

CONCLUSION

The objective of dose assessment is to provide the decisionmaker with information necessary to determine effective protective actions. The objectives of protective actions are to mitigate the consequences of a nuclear accident and ensure that radiation exposure to the public will be as low as reasonably achievable (ALARA).

The decisionmaker, to be effective, must combine the objectives of dose assessment and protective actions---neither stand alone. The combination places emphasis on the need for an effective interface between health physics and meterology. This interface is necessary to provide the decisionmaker with radiological data required to implement and/or modify offsite protective actions. This information is derived from meteorological data and onsite radiation measurements used in the initial dose projections and later supplemented with confirmatory radiological data based on in situ monitoring of the offsite environs.

OVERVIEW OF THE INTERFACE BETWEEN RELEASE CHARACTERISTICS AND METEOROLOGY

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U.S. Nuclear Regulatory Commission

I've been asked to present a so called keynote presentation on the subject of the above title. So that you can understand the viewpoint from which I made this presentation, let me briefly provide my background. I'm trained as a nuclear physicist, who for the past nine years with AEC and NRC has been associated with the Radiological Assessment Branch, Later the Accident Evaluation Branch, and Effluent Treatment Systems Branch. During part of this experience I have had responsibility for the Hydrology-Meteorology Branch, and the Meteorology Section of Accident Evaluation Branch. The groups mentioned have to evaluate and develop methodologies for the assessment of radiation exposure to individuals and population groups from both normal operation and accidents of NRC licensed nuclear power plants. Essential elements of these evaluations are the release characteristics and constituents, transport, diffusion, deposition and receptor aspects, all of which are treated in one way or another in this workshop. During the time I have been at AEC and NRC, we have wrestled with the issue of proper balance between the accuracy needed in the final answer, dose to persons and to populations and the accuracy of the inputs in terms of sources of radioactivity, release conditions, dispersion and deposition characteristics and all the elements of pathways and parameters for exposure to and uptake in humans.

The accuracy to which results are needed is dependent considerably on which one of the situations is being treated. I have mentioned above, the following calculational situations:

1. Assessment of radiation exposure to individuals and populations due to normal operational releases of radioactive effluents from nuclear power plants.

   In this case the releases are very small, and relatively accurately known, due to both measurements in plant and at effluent release points and to known characteristics of radioactive waste treatment systems. Releases are random throughout the year, but are from well known release points, or are controllable to accommodate to known dispersion conditions when desired or necessary.

2. Assessment of potential radiation exposure to individuals and populations due to predicted or postulated accidents at nuclear power plants.

   The newly developed NEPA accident risk and consequent calculations use the CRAC code and site specific population factors and meteorology in order to determine consequences of accidents having differing probabilities of occurrence. These calculations include considerations of action taken by the population under emergency planning guidance. Often, the release conditions have to be assumed since the release point or facility integrity are not necessarily likely to be known.

3. Assessment of releases and potential exposures for events actually in progress.

   In this case, for which the NRC's emergency response mechanism has been formulated, information is being fed in from the facility on the course of events in progress. Meteorology data is available and the desire may be to look ahead to a release that may not yet have started but may be the projected consequence of the events in progress. In these cases, the results of calculations going on in real time are needed to make recommendations on mitigation actions in the near term.

Each of these cases has unique interface problems between release characteristics, dose assessment methodology, and meteorological input. This latter interface, i.e., between dose assessment and meteorology has to my mind been a much more significant problem in the NRC. For most of the last nine years that I have been associated with the radiological assessment effort, the dose methodologists and the meteorologists have worked somewhat independently. Dose assessment methodology is treated in R.G. 1.109, and and meteorology in R.G. 1.111. However, (only) in the case of tall stack releases, the dispersion methodology is coupled into R.G. 1.109. D/Q and X/Q have in the past been developed as independent parameters which can be given to the dose assessment reviewer. This has forced certain assumptions such as receptor immersion in a semi-infinite cloud, rather than either an elevated plume or a finite defined cloud. Recently Walt Pasciak and Earl Markee have been developing a computational methodology that is able to more appropriately accommodate to the likely real condition. This has had the impetus of the need to develop accident calculations for emergency response conditions. In this kind of teamwork, we would expect that a proper balance of accuracy and sensitivity to various aspects of release, dispersion, deposition and pathway analysis can be developed.

I would like to speak for a moment about the accuracy issue. In calculating radiation dose to receptors or population groups, there are generally built in conservatisms where certain parameters are not well known so that it can be comfortably defended that the whole calculational process is resulting in doses that are not underestimates. Even with many internal interactions in NRC between the release predictors, the meteorologists, and the dose assessment people, we have had a great deal of difficulty in keeping a uniform balance of input accuracy and output need. Doses should be presented to one significant figure, to properly characterize their accuracy, with the realization that the values may actually be conservative to a factor of two or more. Under these conditions, it hardly seems justified to continually refine associated or input parameters.

The probable greatest overall weakness in the determination of risk associated with releases of radioactivity from nuclear facilities is the lack of verification of the results. There are very few examples of cases where radiological releases have been measured well at the release point, followed well with meteorological data appropriate to the dispersion condition, and then measured accurately and sensitively at the potential point of uptake by man. In one such case, in an experiment carried out at Quad Cities plant, iodine was measured in milk after a relatively controlled release with all parameters measured. For other isotopes and for other pathways to man, only individual parameters along a pathway have been measured, but no beginning and end point verifications.

It is hoped that verification can be the trust of future research projects. For normal operational releases from power plants, the measurement is difficult at the receptor end where extremely small values of radioactivity deposition and uptake make it almost impossible to do good verification. Nevertheless, every reasonable opportunity should be taken to do this important task.

RELEASE CHARACTERISTICS AND ATMOSPHERIC DISPERSION

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EXTENDED ABSTRACT

Attention is confined to effluents emitted in the immediate vicinity of buildings, so that the near-building flow field has a strong influence on the path and diffusion of the released material. Several questions arise:

* how do building geometry and effluent characteristics affect the flow and concentration patterns?

* can concentrations close to building surfaces be predicted or at least bounded?

* can near-wake concentrations be estimated?

* how rapidly does the building influence on far-wake concentrations disappear?

Considerable attention must be devoted to understanding the flow fields near buildings, since these control the initial plume trajectory and diffusion, and influence the dispersion downwind. Recent visualizations of the flow near simple block-like structures are presented and discussed. The along-wind length of the building is important since reattachment of initially separated roof and side flows is not possible if the building is short. If reattachment does not occur, the recirculating wake cavity contacts the roof and sides of the building as well as the lee face. If reattachment does occur, then more or less isolated roof and side wall recirculation zones appear on the upwind portion of those surfaces, and the wake cavity contacts only the lee face. Vortices are generated at the upwind building face and behind its lee edges; their behavior is still under investigation.

Changes in building geometry lead to quite different flow fields and concentration patterns. The location of flow reattachment zones is especially important, since the presence of reattachment significantly affects the near-surface flow direction and hence the effluent path. Even fairly small changes in architecture, such as an equipment housing on a previously open roof, can drastically alter the flow.

The location, height, and exit characteristics of an exhaust vent serve to place released material into a particular location within the complex flow field; even small changes in these parameters can sharply alter the concentration patterns. The effect of different stack positions, heights, and exit speeds on plume path and dispersion is illustrated for a simple building. If the wind strikes the building

at an angle, the near-roof flow is complicated by vortices generated at the windward roof corner. These transfer material emitted from stacks back to roof level and then into the building wake; fairly tall stacks or rather high exit speeds may be needed to avoid high concentrations.

For the simple case of flush roof vents on a block-like building, one can estimate the maximum concentration (or minimum dilution) likely to occur, regardless of the specific geometry, for normal wind incidence. Wilson's suggestion

$$D_{min} \cong 0.11\ K_e\ s^2/A_p,$$

where K_e is the nondimensional concentration at the vent exit $= (U_H A_p)/(w_e A_e)$, s is the "stretched string" source-receptor distance, and A_p is the structure's projected frontal area, is an adequate lower bound to nearly all the available data, and is much less conservative than Halitsky's earlier recommendation. The expression overpredicts dilution when the wind is at an angle θ to the building centerline, but Li et al. have shown that dividing Wilson's expression by $1 + \theta/(\pi/4)$ provides a good lower bound on the dilution for these cases as well.

If the roof exhaust point is located well away from the edges and is well downwind of the roof recirculation cavity, it is possible to estimate the additional dilution provided by a stack as opposed to a flush vent. One can also estimate the changes in dilution due to changes in stack height. The expressions are described and a reference to a more detailed discussion is given.

When buildings are complex, no reliable simple guidelines are presently available. The most satisfactory approach is a laboratory modeling effort, carefully executed, with recourse to site-specific field data whenever feasible.

Within the recirculating wake cavity, most estimates for concentration assume $K \cong$ constant between 0.2 and 2. These values agree with data, but cannot account for variations with building shape. They also assume full entrainment of the emitted material into the wake cavity, which is not always true, especially during periods of intermittent downwash of an elevated plume. Two models which partially account for building shape are available and these are described.

Downwind of the cavity, wake concentration is not even approximately uniform. If the release is not completely entrained, Briggs' technique for calculating effective stack height can be employed, and the result can then be used in the Gaussian plume expression for an elevated source. If the effluent is completely captured in the cavity, several models are suggested: the "virtual source" method, the plume "initial dilution" technique, and the "total diffusion parameter" approach. The second of these is the most widely applied; it predicts that the wake centerline ground-level concentration is given by

$$\chi = Q \,/(\pi\sigma_y\sigma_z + cA_p)U,$$

where c is between 1/2 and 2. Wind tunnel and field tests suggest that c = 1/2 to 1 works well for simple structures, although the model did not correlate well with field and tunnel data for a building complex. An NRC-suggested variation uses $c = 1/\{2 + 3(d/s)^{1.4}\}$, where d is the diameter of a containment building, and s is the vent-to-receptor distance. This model, however, is based on possibly inadequate wind tunnel simulations of a rounded reactor building obtained over a small range of variables. Its use should therefore be restricted to similar circumstances, and may not be totally correct even there.

In many cases, the data indicate that the plume will be neither completely elevated or entrapped by the building wake; instead, a fluctuating partial entrainment may occur. The "split-h" model of Johnson <u>et al.</u> accounts for the resulting two different effective release heights. If, in a given hour, a fraction M of the plume is entrained in the wake, then the average concentration for the hour is

$$(\chi/Q)_{ave} = M(\chi/Q)_{entr} + (1-M)\ (\chi/Q)_{elev}.$$

The entrained concentration is calculated from a ground-level enhanced diffusion model, and the elevated concentration is computed from a Gaussian model using the corrected effective emission height. The entrainment fraction M depends on parameters such as effluent exit to wind speed ratio, stack to building height ratio, and the specific building geometry and atmospheric conditions. Extrapolations of empirical estimates of M from one site to another will probably be wrong.

Huber and his colleagues have developed expressions for the Gaussian dispersion parameters which incorporate the influence (and its decay with downwind distance) of the building wake. They suggest that, downwind of the cavity, but for $x \leqq 10$ H,

$$\sigma_y' = 0.7\ (W/2) + 0.067\ (x-3\ H)$$

$$\sigma_z' = 0.7\ H + 0.067\ (x-3\ H).$$

For x > 10H, a virtual source model is used. The expressions for σ_y' and σ_z' are used in the Gaussian plume model. If the effective source height is ≦ H, both horizontal and vertical plume enhancement are assumed, while for release heights > H, only vertical enhancement is allowed. For source heights < 1.5 H or so, agreement with laboratory data is fairly good for simple buildings, but discrepancies appear behind building clusters. Agreement with field data ranges between poor and good on a case-by-case basis, probably because most of the field work has dealt with building complexes, rather than single structures.

Far downwind, there is no really satisfactory way to predict building wake concentrations. Model design is difficult because of discrepancies between laboratory and field data, and an inadequate understanding of far-wake phenomena. One possible explanation for the relatively rapid drop-off with distance of real-world concentration data is wind meander, which is a major contributor to plume dilution, but is impossible to duplicate in the laboratory. However, it is possible to generate time-average concentrations from wind tunnel data at various angles of wind incidence, time-weighted with site-specific meteorological data. Work by Bouwmeester et al. looks promising, and should be extended. Another possible explanation involves organized wake vortices. These may be more persistent in the laboratory than the atmosphere, but they may also be undetected in field experiments confined to ground level sampling. If vortices are important, new far-wake concentration models must reflect this; if they are not important, relatively simple models will suffice. More information is needed before the situation can be resolved.

A number of recommendations are made:

* lab and field work should emphasize flow patterns near buildings.

* measurements of phenomena such as reattachment, downwash and its intermittency, etc. are needed for various building shapes.

* the estimate for minimum dilution should be further tested, although it is adequate for interim use.

*data from flush vent and stack releases are needed to use the method for evaluating the benefit of stack height changes.

* a better understanding of cavity flows and more data are needed to use and improve present cavity concentration models.

*field studies of far wakes are needed to establish the importance of persistent vortices; laboratory studies of atmospheric effects on far wake persistence are also needed.

* the method for combining lab data and on-site meteorological data to estimate time-averaged wake concentrations should be further tested.

* flow phenomena in building clusters should be systematically studied, so that appropriate wake concentration models can be developed.

Overview of Transport, Diffusion, and Deposition

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Deciding on an appropriate course of action in response to an atmospheric release of any pollutant involves a series of decisions that must be made quickly, on the basis of available information, and in a conservative manner. It is first required to identify the direction in which the released material is moving, and then to estimate its rate of spreading in order to identify areas in which the population and the environment may be at risk. The development of suitable models has been a major goal of recent meteorological research. A wide range of models of greatly varying complexity is now available, yet the fundamental transport, diffusion and deposition phenomena that they describe are not yet fully understood. Furthermore, it is often not clear how to decide the circumstances in which a selected model will be applicable, or to select which model will best apply in a given set of conditions.

The transport and diffusion processes of importance here have been investigated in field experiments that have tended to fall into either of two broad categories, "holistic" (or "integral") investigations of plume behavior in selected circumstances, or "reductionist" studies of the processes that control various aspects of plume behavior. In the first category, we can include most of the site-specific dispersion studies that have been conducted in connection with particular nuclear projects. In the latter are investigations of planetary boundary layer structure, such as the Wangara and Minnesota PBL experiments. Most recent dispersion studies have attempted to combine aspects of each philosophy; tracer studies are used to evaluate dispersion directly, while turbulence measurements and surface flux data provide a means to extrapolate dispersion data to circumstances that are not yet studied. In recent years, large PBL studies have included studies of tracer plumes (e.g. the RUSH/AMBIENS study in Southern Indiana in 1977) and studies of plume dispersion have had supporting PBL and surface boundary layer data (e.g. the 1980 Idaho Falls plume studies).

The development of rational models suitable for emergency response is hindered by the general lack of data obtained in other than simple cases. Work such as that mentioned above has largely succeeded in documenting dispersion characteristics over horizontally-uniform, flat surfaces, with vegetation of limited density and height. The real world presents problems that have not been overlooked, but progress towards their solution has been slow. There are three main problems that need to be addressed: non-stationary conditions, non-simple terrain, and non-simple surface texture. Of these, only the question of "complex terrain" is currently receiving substantial attention, yet the other factors are intimately coupled with it. All of these factors need to be investigated in carefully constructed, dedicated, and directed field experiments because in practice it is often impossible to relate effects to any particular cause when several possible causes are jointly influencing the overall behavior. Thus, considerations of the "holistic" and "reductionist" philosophies again arise, and once more there is room for both kinds of activity and a need for each to recognize the demands of the other. An example of current relevance is the drainage flow problem, as investigated in the DOE "ASCOT" program. Field experiments conducted in the Geysers region of northern California supported the expectation that occurrences of drainage flow in forested terrain would be less frequent and less intense than predictions based on simple-surface meteorology. In this case, the combination of trees and complicated topography superimposed two areas of uncertainty in a manner that makes unravelling quite difficult. Attempts to determine major causative factors are usually even more difficult than the ASCOT example implies, since the main driving forces are associated with diurnal cycles and hence the problem of flow in valleys and around hills is intimately coupled to the question of non-stationarity.

In geographical situations of practical interest to the nuclear power industry, the meteorological dispersion and deposition problems are complicated by the nearby presence of water. Rivers provide preferred routes for channeling the flow of airborne material. Shoreline sites impose perhaps the most difficulties of all complex terrain situations, since in this case the land and water surfaces differ in almost all important respects. Stability regimes are completely different, as are surface roughnesses and deposition rates of both particulate and gaseous pollutants. Dynamical features of flow in coastal regions have received a lot of attention, especially recently with the advent of new remote-probing techniques. However the matter of the dry deposition rate of airborne particles to water surfaces remains unresolved. In fact, it is difficult to find a situation in which there is general consensus regarding the deposition velocity appropriate to describe particle fluxes in given circumstances. It is fortunate, perhaps that this is not a critical matter in considerations of nuclear emergency response. However, the same cannot be said of wet deposition. A question that might well be asked of all who advocate specific responses to emergencies is "What happens if it rains?".

ATMOSPHERIC TRANSPORT MODELING

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If there is an emergency at a nuclear power plant two questions that are likely to be asked are: If material is released, where will it go? and How long would it take to reach some receptor of interest? These are the basic questions that atmospheric transport modeling attempts to answer. The purpose of this presentation is to describe various approaches to transport modeling. In the discussion we will make several assumptions. These assumptions are:

1. The release time and height are known,
2. The released material travels with the wind,
3. The plume can be adequately represented by the centers of mass of plume segments or puffs.

With these assumptions, the problem to be solved in transport modeling becomes one of specifying the transporting wind.

Wind field models range in sophistication from the simple straight-line transport assumption used in most nuclear facility licensing studies to approximate solutions of the equations of motion in three dimensions. There is a continuum of wind field models on the scale, but the models can loosely be grouped into several categories. Nominally these are:

- Uniform wind field
- Area of influence
- Interpolation
- Simplified physics
- Full physics

The sophistication of the models increases from the top of the list to the bottom. In general, the computational load and computer time required to generate the wind field also increase as you go down the list.

Uniform wind field models use a single wind speed and direction to define the air motion everywhere within the model's domain. These models are relatively common because they are easy to use and require very little input data. Although there is no spatial variation of the wind field, the wind field may vary in time. If there is no temporal variation of the wind field, the trajectories of plume sections are straight. If there is temporal variation of the field, the trajectories followed by individual sections of the plume will be curved, and the plume may assume irregular shapes.

There are many cases where these models provide an adequate description of the actual wind field. However, there are also cases where the actual wind field is known to vary spatially. The remaining modeling approaches have been developed for the general case in which the wind field may or may not vary in space.

The simplest model that includes spatial variation of the wind field is the area of influence model. In essence, the area of influence model is an extension of the uniform field model. The total region of interest is divided into several smaller areas, and a uniform wind field model is used in each area. It is not necessary for the winds in all of the areas to be identical. Thus, spatial variability is introduced without significantly increasing model complexity.

The area of influence wind field model is intuitively more realistic than the uniform field model, but its adequacy depends on the skill of the individual setting the area boundaries and the availability of wind data from more than one location. In a region where the factors affecting wind fields and their effects are obvious, boundaries may be relatively easy to establish. Where the factors and their effect are subtle, setting area boundaries is likely to be difficult. The number of areas that can be established within a region depends on the number of available wind instruments and their locations. A wind instrument is required for each region, and it should be located in a position that gives a wind measurement that is representative for the region.

The notion of areas with different wind regimes is realistic, but the concept of distinct boundaries between the area is artificial. Wind field interpolation models avoid this artificiality. In an interpolation model, the wind at any point is represented by averaging the observed winds at nearby instruments. There are any number of ways to do the averaging; one common method uses weighted average where the weights are inversely proportional to the distances from the measurement locations.

In general, the area of influence and weighted-average interpolation models are two dimensional models that treat only the horizontal components of wind. There are more complex interpolation models that are fully three dimensional. These models require upper level wind data as well as surface data. They also generally place constraints on the interpolation. The most common constraint is the conservation of mass. Following an initial estimate of the wind field using weighted average interpolation techniques, the field is adjusted so that the air mass in each small volume is conserved.

In the area of influence model and the less complicated interpolation models, the effects of terrain are not treated explicitly. If the wind instruments used to provide data for the models are properly located and there is a sufficient number of instruments, they should be included implicitly. Terrain is treated explicitly in the more complex interpolation models.

Each of these three approaches to modeling wind fields emphasizes the analysis of wind data, and none of them can reproduce features of the actual wind field that are not represented in the data used by the models. The two remaining approaches to modeling wind fields place significantly more emphasis on the physics of the flow. To be sure they still require data, but the emphasis has changed to the use of the equations of motion and thermodynamic equations to estimate the wind affecting plume segments.

The simplified physics and full physics approaches to wind field modeling both start with the equations of motion and the thermodynamics equations. The full physics approach attempts to solve the equations in their complete form. This takes significant computer resources and requires a relatively long time. As a result, the full physics approach to wind field modeling is probably not reasonable for use in emergency response applications with current computer technology.

In the simplified physics models, a number of assumptions are made to make the solution of the equations more tractable.

In one model, the atmosphere is considered to be a single layer. A uniform background wind speed and direction are imposed at the top of the layer. The surface level winds are then derived by successive superposition of disturbances caused by terrain, surface friction and thermal forces.

The selection of a wind field modeling approach for emergency response applications involves trade-offs between model accuracy and the costs associated with data collection, model execution and the time required to obtain transport estimates. Intuitively, we would expect model accuracy to increase as more information is included. Unfortunately, the relationship between model complexity and model accuracy has not been established. Simple wind field models will frequently provide adequate transport estimates; we do not know how increasing model complexity increases the percentage of the time that adequate estimates of transport will be provided. On the other hand, we do know that transport estimates can be obtained quickly from small computers when the less complex interpolation and simplified physics wind field models are used.

SPECIAL CONSIDERATIONS OF ATMOSPHERIC DIFFUSION

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Extended Abstract

Numerous nuclear reactor sites are located along the shores of the Great Lakes, the Gulf of Mexico, and the Atlantic and Pacific Oceans. As compared to flat inland sites, the coastal locations exhibit particularly complex spatial and temporal changes of parameters such as wind speed, wind direction, surface roughness, air temperature, and atmospheric diffusion rates. In these cases the use of a relatively simple diffusion model such as the straight-line Gaussian cannot be effectively used on a real-time basis without appropriate modification and adaptation. The chief cause for this complexity is the existence of an extensive land-water interface causing differential heating between the air over the land and over the water. In the case of the cooler air over the water and warmer air over the land, an inflow of air from the water towards the land is initiated. A return flow above the inflow completes the cell-like circulation with rising air at the inland edge and descending air at the overwater limit of the cell. The inland flow is further complicated by the buildup of an unstable layer due to heat from the land surface. As the flow progresses inland a boundary is created between the turbulent lower layer and the unaffected stable layer above.

Two specific diffusion situations at a coastal site can arise. First is the situation where the height of the turbulent boundary layer is above the emission point of the effluent which traps the vertical growth of the effluent between the surface and the overlying stable air. The second situation is when the effluent is emitted above the turbulent boundary layer which can result in a fumigation process as the turbulent layer deepens as it progresses inland. It is clear that a real-time coastal transport and diffusion model should include measurements and/or calculations of the following: (1) the height of the internal boundary layer as a function of inland distance, (2) the trajectory and inland extent of a plume in the sea or lake breeze flow, (3) the differing diffusion rates in the marine and continental air, (4) the height and trajectory of the upper air return flow towards the water, (5) the wind speeds in the sea breeze flow and the return flow aloft, and (6) the three-dimensional trajectory of the helical circulation formed by the sea breeze circulation.

At this time there does not appear to be any verified model which predicts, in real time, the onset of the sea breeze, its inland penetration and trajectory, and the helical circulation of the phenomenon.

Because of the need for coolant water, many reactor sites are located in pronounced river valleys such as those in the Appalachian Mountain chain in the eastern United States. Of primary concern is the channeling of the air flow within the valley and the flow reversals that occur as a function of diurnal heating and cooling of the valley surfaces. Another feature that must be considered is the decoupling of the valley flow from the pressure gradient flow above the valley ridges.

As was the case in the sea breeze flow, a simple straight-line Gaussian diffusion model is not adequate to describe the restricted downvalley transport and diffusion of an effluent released within the confines of the valley. An adequate real-time valley dispersion model should include the following measurements or calculations: (1) the height and width of the valley stable layer as a function of downwind distance, (2) the orientation of the valley axis as a function of downwind distance, (3) the wind speed and direction profile within and above the valley confines, (4) the differing diffusion rates within and above the valley confines, (5) the downvalley extent of the restricted flow, and (6) the time of the diurnal flow reversals.

Of all the special site characteristics discussed so far, the complexities of mountainous terrain makes each site a special case. In addition to having slope flows similar to valley flows, numerous other terrain induced flows can exist such as air flow around and over terrain obstacles, plume impaction on blocking terrain, channeling and venturi effects, flow affected by hydraulic jumps, lee waves and rotors, and valley air stagnation. The roughness of the terrain as well as the vegetative cover and orientation of the slope to the sun has a pronounced effect on the atmospheric diffusion rates.

It is clear that the determination of real-time effluent trajectory (transport) and diffusion requires not only the appropriate mathematical models for the situation at hand, but also the availability of the appropriate meteorological measurements which serve as either direct input to the model or as the means to parameterize the model variables.

PRECIPITATION SCAVENGING PARAMETERS FOR REACTOR RELEASE MODELING

M. Terry Dana

ABSTRACT

A review of the current state of knowledge of precipitation scavenging processes suggests that the most practical parameter for application to reactor accident release assessments is the scavenging or "washout" ratio -- the ratio of precipitation concentration to air concentration. For aerosols -- both in-cloud and below-cloud scavenging -- the suggested dimensionless ratio (r) ranges from 0.5 to 5×10^6. For gases, however, there is a considerably wider range to consider. I_2 scavenging has not been studied to sufficient detail, but by analogy to SO_2 it appears that r should be about 10^3 at 25°C. Suggested values for HTO, HT, and CH_3I are 2×10^4, 0.02, and 2, respectively, (0°C). Chemically active gases should be expected to be removed at a greater rate, and -- particularly I_2 -- become attached to aerosol particles. Adequate prediction of wet deposition depends crucially on the plume descriptor model employed.

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The Workshop on Meteorological Aspects of Emergency Response Plans for Nuclear Power Plants was held December 1-3, 1981, at SRI International in Menlo Park, California. The purpose of the workshop was to collect and integrate the comments of the user community on the Nuclear Regulatory Commission's (NRC's) atmospheric dispersion modeling requirements in support of nuclear power plant radiological emergency response plans. The user community was represented by utilities, consultants, and state and federal government agencies. The workshop was organized into five short introductory technical sessions, followed by working sessions. The technical sessions provided an overview of the state of the art in health physics; release characteristics; transport, diffusion, and deposition; and operational aspects. The three working groups addressed the themes of health physics and meteorology, release characteristics and meteorology, and dispersion and deposition. This report summarizes the activities and results of both parts of the workshop.

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