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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before Administrative Judges:
Ivan W. Smith, Chairperson
Gustave A. Linenberger, Jr.
Dr. Jerry Harbour

In the Matter of PUBLIC SERVICE COMPANY OF NEW HAMPSHIRE, ET AL. (Seabrook Station, Units 1 and 2)	Docket Nos. 50-443-444-OL (Off-site EP) April 25, 1988

COMMONWEALTH OF MASSACHUSETTS TESTIMONY OF STEVEN C. SHOLLY ON THE TECHNICAL BASIS FOR THE NRC EMERGENCY PLANNING RULES, DR. JAN BEYEA ON POTENTIAL RADIATION DOSAGE CONSEQUENCES OF THE ACCIDENTS THAT FORM THE BASIS FOR THE NRC EMERGENCY PLANNING RULES, AND DR. GORDON THOMPSON ON POTENTIAL RADIATION RELEASE SEQUENCES

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[Testimony of Sholly, and Beyea and Thompson on Sheltering]

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I. IDENTIFICATION OF WITNESSES

Q. Please state your names, positions, and business addresses.

A. (Sholly) My name is Steven C. Sholly. I am an Associate Consultant with MHB Technical Associates of San Jose, California.

A. (Beyea) My name is Dr. Jan Beyea, I am the Senior Energy Scientist for the National Audubon Society in New York City.

A. (Thompson) My name is Dr. Gordon Thompson. I am Executive Director of the Institute for Resource and Security Studies in Cambridge, Massachusetts.

Q. Briefly summarize your experience and professional qualifications.

A. (Sholly) I received a B.S. in Education from Shippensburg State College in 1975 with a major in Earth and Space Science and a minor in Environmental Education. I have seven years experience with nuclear power matters. In particular, for four and one-half years I was employed by the Union of Concerned Scientists where I worked on matters related to the development of emergency plans for commercial nuclear power plants and the application of probabilistic risk assessment (PRA) to the analysis of safety issues related to commercial nuclear power plants. I have been a consultant with MHB Technical Associate for two years, during which time I have been involved in a variety of projects related to the safety and economics on nuclear power plants, including the evaluation of severe accident issues for light water nuclear power plants generally, and for the Seabrook Station, Unit 1, specifically.

I have testified as an expert witness in proceedings before the U.S. Nuclear Regulatory Commission (NRC) and other bodies, including the safety hearings on Indian Point Units 2 and 3 (Docket Nos. 50-247-SP and 50-286-SP), the licensing hearings on Catawba Nuclear Station, Units 1 and 2 (Docket Nos. 50-413 and 50-414), and the licensing hearings on the Shoreham Nuclear

Power Station, Unit 1 (Docket No. 50-322-OL-3). I have also provided expert testimony before the Sizewell B Public Inquiry in the United Kingdom. I have served as a member of a peer review panel on regulatory applications of PRA (NRC report NUREG-1050), as a member of the Containment Performance Design Objective Workshop (NRC report NUREG/CP-0084), as a member of the Committee on ACRS Effectiveness, and as a panelist at the Severe Accident Policy Implementation External Events Workshop, Annapolis, Maryland (presentation on seismic risk assessment, 1987; forthcoming Lawrence Livermore National Laboratory report). The details of my education, experience, and professional qualifications are included in my resume, which is contained in attachments to this testimony.

(Beyea) I received my doctorate in nuclear physics from Columbia University in 1968. Since then I have served as an Assistant Professor of physics at Holy Cross College in Worcester, MA; as a member for four years of the research staff of the Center for Energy and Environmental Studies at Princeton University; and, as of May 1980, as the Senior Energy Scientist for the National Audubon Society.

While at Princeton University, I worked with Dr. Frank von Hippel to prepare a critical quantitative analysis of attempts to model reactor accident sequences. The lessons learned from this general study of nuclear accidents and the computer codes written to model radioactivity releases were then applied by me to specific problems at the request of governmental and non-governmental bodies around the world. I have written major reports on the safety of specific nuclear facilities for the President's Council on Environmental Quality (TMI reactor), for the New York State Attorney General's Office (Indian Point), for the Swedish Energy Commission (Barsebeck reactor), and the state of Lower Saxony (Gorbleben Waste Disposal Site). I have also examined safety aspects of specific sites for the California Energy and Resources Commission, the Massachusetts Attorney General's Office and the New York City Council.

While at Princeton, I wrote a computer program useful for reactor emergency planning for the New Jersey Department of Environmental Protection. This program, appropriately modified, has been used for some of the calculations presented in this testimony.

After joining the National Audubon Society, I continued to work as an independent consultant on nuclear safety issues. I participated in a study, directed by the Union of Concerned Scientists at the request of the Governor of Pennsylvania, concerning the proposed venting of krypton gas at Three Mile Island. The U.S.C. study, for which I made the radiation dose calculations, was the major reason the Governor gave for approving the venting.

I participated in the international exercise on consequence modelling (Benchmark Study) coordinated by the Organization for Economic Cooperation & Development (O.E.C.D.). Scientists and engineers from fourteen countries around the world calculated radiation doses following hypothetical "benchmark" releases using their own consequence models. Participants from the United States, in addition to myself, included groups from Sandia Laboratories, Lawrence Livermore Laboratory, Batelle Pacific-Northwest, and Pickard, Lowe and Garrick, Inc. I also served as consultant from the environment community to the N.R.C. in connection with their development of "Safety Goals for Nuclear Power Plants."

At the request of the Three Mile Island Public Health Fund, I supervised a major review of radiation doses from the Three Mile Island Accident. This report, "A Review of Dose Assessments at Three Mile Island and Recommendations for Future Research" was released in August of 1984. Subsequently, I organized a workshop on TMI Dosimetry, the proceedings of which were published in early 1986.

In 1986, I developed new dose models for the Epidemiology Department of Columbia University. These models are being used to assess whether or not the TMI accident is correlated with excess health effects in the local population. The new computer models account for complex terrain, as well as time varying meteorology (including changes in wind direction). Insights gained from this project have been applied to the Seabrook situation.

In addition to reports written about specific nuclear facilities, an article of mine on resolving conflict at the

Indian Point reactor site, an article on emergency planning for reactor accidents, and a joint paper with Frank von Hippel of Princeton University on failure modes of reactor containment systems have appeared in The Bulletin of the Atomic Scientists.

I have also prepared risk studies covering sulfur emissions from coal-burning energy facilities. And I have managed a project that analyzed the side effects of renewable energy sources.

I regularly testify before congressional committees on energy issues and have served on several advisory boards set up by the Congressional Office of Technology Assessment.

I currently participate in a number of ongoing efforts aimed at promoting dialogue between environmental organizations and industry.

I was assisted in the early stages of my studies of Seabrook by Brian Palenik, who has worked with me on other reactor studies in the past. In subsequent answers to questions, I will use the pronoun, "we," to describe our collective efforts. However, all work was carried out either by me or under my direct supervision.

Brian Palenik received his Bachelor of Science in Civil Engineering degree with honors from Princeton University. While an undergraduate at Princeton, Mr. Palenik worked with me on "The Consequences of Hypothetical Major Releases of Radioactivity to the Atmosphere from Three Mile Island"--my report to the President's Council on Environmental Quality.

After graduation, Mr. Palenik joined the staff of National Audubon's Policy Research Department. While there, he and I wrote, "Some Consequences of Catastrophic Accidents at Indian Point and Their Implications for Emergency Planning," as part of our testimony before the Nuclear Regulatory Commission Atomic Safety and Licensing Board, July 1982.

Mr. Palenik is currently a graduate student in the Civil Engineering Department at M.I.T.

A complete resume is included in the attachments to this testimony.

(Thompson) I received a Ph.D in applied mathematics from Oxford University in 1973. Since then I have worked as a consulting scientists on a variety of energy, environment, and international security issues. My experience has included technical analysis and presentation of expert testimony on issues related to the safety of nuclear power facilities.

In 1977, I presented testimony before the Windscale Public Inquiry in Britain, addressing safety aspects of nuclear fuel reprocessing. During 1978 and 1979, I participated in an international scientific review of the proposed Gorleben nuclear fuel center in West Germany, this review being sponsored by the government of Lower Saxony.

Between 1982 and 1984, I coordinated an investigation of safety issues relevant to the proposed nuclear plant at Sizewell, England. This plant will have many similarities to the Seabrook plant. The investigation was sponsored by a group of local governments in Britain, under the aegis of the Town and Country Planning Association. This investigation formed the basis for testimony before the Sizewell Public Inquiry by myself and two other witnesses.

From 1980 to 1985, first as a staff scientist and later as a consultant, I was associated with the Union of Concerned Scientists (UCS), at their head office in Cambridge, MA. On behalf of UCS, I presented testimony in 1983 before a licensing board of the US Nuclear Regulatory Commission (NRC), concerning the merits of a system of filtered venting at the Indian Point nuclear plants. Also, I undertook an extensive review of NRC research on the reactor accident "source term" issue, and was co-author of a major report published by UCS on this subject (Sholly and Thompson, 1986).

Currently, I am one of three principal investigators for an emergency planning study based at Clark University, Worcester, MA. The object of the study is to develop a model emergency plan for the Three Mile Island nuclear plant. Within this effort, my primary responsibilities are to address the characteristics of severe reactor accidents.

My other research interests include: the efficient use of energy; supply of energy from renewable sources; radioactive waste management; the restraint of nuclear weapons proliferation; and nuclear arms control. I have written and made public presentations in each of these areas.

At present, I am Executive Director of the Institute for Resource and Security Studies, Cambridge, MA. This organization is devoted to research and public education on the efficient use of natural resources, protection of the environment, and the furtherance of international peace and security.

A detailed resume is included in the attachments to this testimony.

II. <u>CONTENTIONS</u>

Q. To what contentions does your testimony refer?

A. (All) Town of Hampton revised contention VIII, SAPL revised contention 16 and NECNP contention RERP-8. These contentions and their bases are set out in full in Attachment 4. Our testimony also addresses matters raised in the Federal Emergency Management Agency (FEMA) June 4, 1987 "current" position on these contentions. In addition, our testimony bears on aspects of other contentions in this proceeding.

Q. What is the purpose of your testimony and how does it relate to the specific contentions cited here?

A. (All) These three interrelated contentions and the FEMA position on them all concern the issue of protection from radiological releases of the beach populations in the vicinity of the Seabrook Plant. Our testimony first describes the standard guidance used by the Nuclear Regulatory Commission (NRC) and FEMA for the initiation and duration of radiological releases to be considered in emergency planning. Then, and using postulated accidents at Seabrook consistent with the spectrum of accident scenarios called for in the NRC guidance, the testimony estimates and describes the radiation dosages which could affect the beach populations near the Seabrook Plant site.

The testimony as a whole demonstrates that NHRERP Rev. 2 is fundamentally flawed and is of no real or practical use because the beachgoing public in the vicinity of the Seabrook plant will not be adequately protected in the event of an emergency. In particular, this testimony shows that because of the size of the beach population in the immediate vicinity of the plant site, the long evacuation times, and the lack of effective sheltering, many thousands of individuals will die, suffer serious injuries or face the prospect of increased likelihood of cancer if one of any number of the accidents required to be planned for by the NRC occurs. Thus, because of the radiation dosages that would reach the beach population, there is no reasonable assurance that NHRERP Rev 2 can and will be implemented to provide adequate protection to the public in the event of an accident.

III. OVERVIEW

Q. Please summarize your portion of this testimony.

A. (Sholly) My testimony describes the technical basis for the current NRC emergency planning rules. The testimony discusses the use in the NRC reports NUREG/CR-1311, NUREG-0396, and NUREG-0654, of the risk assessment results for the Surry Unit 1 plant (as set forth in the NRC report WASH-1400) to derive dose-distance relationships for a spectrum of accidents, including severe accidents beyond the design basis of light water nuclear power plants. The testimony further describes the nature of that spectrum of accidents, including release characteristics, release frequencies, and uncertainties. Finally, the testimony describes how the risk-based insights from the Surry Unit 1 risk assessment were utilized by the NRC to arrive at the generic emergency planning zone distances and other guidance contained in the rules and in the applicable NRC guidance documents (including NUREG-0654, Rev. 1).

A. (Beyea) The situation around the Seabrook Nuclear Power Plant is unusual in the context of emergency planning for nuclear plants, because large populations make use of nearby beaches in the summertime. In order to determine the extent of protection afforded the summer beach population by current emergency plans, we have modelled the radiation doses to the population that would follow releases of radioactivity from the Seabrook plant. A range of releases has been studied, patterned after the range used in the NRC's report, NUREG-0396.

In NUREG-0396, a set of generic accident sequences (PWR1-PWR9) were defined that apply to pressurized water reactors like the Seabrook plant. These sequences span the entire range of physically-plausible release scenarios, making them useful for assessing, at least on a theoretical basis, the effectiveness of emergency plans. For my testimony, we have chosen accident sequences that are similar to the NRC's generic versions, but which take into account reactor-specific differences at Seabrook.

In order to understand the conditions under which the population would not be protected from "early death" (death within 60 days of the release), doses were modelled for these release categories using a range of weather parameters, plume rise heights, and dose contribution assumptions. The results indicate that the potential consequences of severe accidents increase greatly during the summer months, due to the increased population in the area and the unique conditions of a beach release: Beach-goers caught in the open would not be shielded from radiation, and could be expected, by our calculations, to receive doses as much as five times higher than generally considered in nuclear emergency planning. This means that certain accident releases, not normally projected to cause early fatalities, are projected to do so in the Seabrook case.

As a result, it is necessary to consider a range of accident scenarios, from those with very small releases to those with very large releases.

In addition to the risk of early death, we have considered other potential accident consequences, including delayed cancer incidence. These potential outcomes dominate the risk for accident releases in classes PWR4-PWR9.

The proximity of the reactor to an unshielded summer beach population makes the Seabrook case a special and difficult one for emergency planning. The doses that would be received following a range of releases at the Seabrook site, with emergency plans in effect, are higher than doses that would be received at most other sites in the complete absence of emergency planning.

Our results demonstrate that, with current plans, the immediate safety of the beach population is threatened for a wide range of releases and meteorological conditions. For the accidents studies in our testimony, many thousand of people could receive life-threatening doses.

A. (Thompson) The issues I address are:

(1) The potential for an atmospheric release, similar to that designated as PWR1 in the Reactor Safety Study, to occur from a steam explosion or high-pressure melt ejection event.

(2) The range of variation of two parameters which affect plume rise during a "PWR1-type" release, specifically the location of containment breach and the thermal energy release rate for the plume.

(3) The potential for "PWR1-type" releases to contain greater amounts of certain isotopes, such as those of ruthenium, than other categories of releases.

IV. <u>SYNOPSIS OF WASH-1400 SURRY ANALYSIS</u>

Q. Please identify and describe the n[illegible] of the NRC report WASH-1400.

A. (Sholly) WASH-1400 (N.C. Rasmussen, et al., <u>Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants</u>, U.S. Nuclear Regulatory

Commission, WASH-1400, NUREG-75/014, October 1975) represents a probabilistic risk assessment of two nuclear power plants, namely Surry Unit 1 and Peach Bottom Unit 2. The report consists of a Main Report and eleven Appendices. WASH-1400 represents the first comprehensive application of probabilistic risk assessment methods to the analysis of the risks posed by commercial nuclear power plants. That is, WASH-1400 includes system analyses, source term estimates, and accident consequence estimates. In the parlance of the NRC's PRA Procedures Guide, WASH-1400 is a Level 3 PRA of two plants.[1/]

Q. Please briefly describe the Surry Unit 1 nuclear power plant and compare its design with that of Seabrook Station, Unit 1.

A. (Sholly) The Surry Unit 1 nuclear power plant is a three-loop, Westinghouse pressurized water reactor with dry, subatmospheric containment. The Surry Unit 1 plant has a design thermal power level of 2441 megawatts, and entered commercial operation in December 1972. Surry Unit 1 is operated by Virginia Power Corporation under operating license DPR-32, issued on May 25, 1972. Seabrook Station Unit 1 is a four-loop, Westinghouse pressurized water reactor with a large,

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1/ Jack W. Hickman, et al., PRA PROCEDURES GUIDE: A Guide to the Performance of Probabilistic Risk Assessments for Nuclear Power Plants, American Nuclear Society and Institute of Electrical and Electronics Engineers, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR 2300, January 1983, pages 2-2 to 2-3.

dry containment. Seabrook has a design thermal power level of 3650 megawatts.

Q. Please summarize the results of the WASH-1400 analysis of the Surry Unit 1 plant.

A. (Sholly) The WASH-1400 report calculated a median core melt frequency for Surry Unit 1 of about 5×10^{-5} per reactor-year (or about 1 in 20,000 per reactor-year).[2/] The NUREG-1150 analysis estimated the core melt frequency for Surry to be 2.6×10^{-5} per reactor year. See, NUREG-1150, draft, page 3-2. The dominant accident sequences for Surry Unit 1 which contributed to this core melt frequency are identified along with their estimated sequence frequencies in Table A, which is attached to this testimony. WASH-1400 also defined nine release categories or source terms which defined the release characteristics and release frequencies for Surry Unit 1. These release categories were designated PWR-1 through PWR-9. Release categories PWR-1 through PWR-7 correspond to

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2/ The Surry core melt frequency estimate in WASH-1400 has been cited as several different values. For instance, the NUREG-1150 report cites a value of 4.6×10^{-5} per reactor year. See M.L. Ernst, et al., Reactor Risk Reference Document, U.S. Nuclear Regulatory Commission, NUREG-1150, Vol. 1, "Main Report", draft for comment, February 1987, page 3-12 (hereinafter "NUREG-1150 draft). A technical report supporting NUREG-1150 cites 4.4×10^{-5} per reactor-year. See, Robert C. Bertucio, et al., Analysis of Core Damage Frequency From Internal Events: Surry Unit 1, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986 page V-68. In fact, as indicated in Attachment 3 to this testimony, if one adds the point estimate frequencies for the WASH-1400 dominant accident sequences, one obtains a core melt frequency of 1.2×10^{-4} per reactor-year.

core melt accidents. Release Categories PWR-8 and PWR-9 are non-core melt accidents, and are roughly equivalent to the design basis accident with (PWR-8) and without (PWR-9) containment spray operation. The Surry release categories are described and their characteristics and estimated frequencies defined in Table B, which is attached to this testimony. Many of the WASH-1400 release categories (especially PWR-1 through PWR-4) could result in significant ground contamination offsite should accidents leading to such releases occur.

V. USE OF WASH-1400 RESULTS IN NUREG-0396

Q. Please identify and describe NUREG-0396.

A. (Sholly) NUREG-0396 (Task Force on Emergency Planning, Planning Basis for the Development of State and Local Emergency Response Plans in Support of Light Water Nuclear Power Plants, U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency, NUREG-0396, EPA 520/1-78-016, December, 1987), set a revised planning basis for commercial nuclear power plants. In essence, NUREG-0396 concluded that a spectrum of accidents should be used in developing a planning basis.[3/]

3/ H.E. Collins, B.K. Grimes & F. Galpin, et al., Planning Basis for the Development of State and Local Emergency Response Plans in Support of Light Water Nuclear Power Plants, Task Force on Emergency Planning, U.S. Nuclear Regulatory Commission and U.S. Environmental Protection Agency, NUREG-0396, EPA 520/1-78-016, December 1978, page 24 (hereinafter "NUREG-0396").

NUREG-0396 recommended the establishment of two generic emergency planning zones (EPZs) for nuclear power plants; a plume exposure pathway EPZ about 10 miles in radius and an ingestion exposure pathway EPZ about 50 miles in radius. These EPZs were designated as "the areas for which planning is recommended to assure that prompt and effective actions can be taken to protect the public in the event of an accident."4/ A significant part of the basis for these planning zone distances was derived from accident consequence analyses (specifically dose-distance calculations) using the WASH-1400 release categories and frequencies for Surry Unit 1.

Q. Please describe how the WASH-1400 results for Surry Unit 1 were utilized in NUREG-0396.

A. (Sholly) The Task Force on Emergency Planning, which wrote NUREG-0396, utilized the Surry Unit 1 results from WASH-1400 to perform consequence calculations to "illustrate the likelihood of certain offsite dose levels given a core melt accident."5/ While the Task Force members debated various aspects of the WASH-1400 report and considered its results to have limited use for plant-and site-specific factors, it was judged to provide "the best currently available source of information on the relative likelihood of large accidental

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4/ Id. at 11.

5/ Id. at 6.

releases of radioactivity given a core melt event."[6/] WASH-1400 results for Surry were also utilized to provide guidance concerning the timing of radiological releases resulting from core melt accidents, and the radiological characteristics of such releases.[7/] The planning basis distance, the time dependent characteristics of potential releases and exposures, and the kinds of radioactive materials that can potentially be released to the environment were identified by the Task Force as the three planning basis elements needed to scope the planning effort.[8/] WASH-1400 results for Surry Unit 1 were used to define all three of the planning basis elements in NUREG-0396.

Q. Please describe the rationale used by the Task Force in establishing the size of the EPZs recommended in NUREG-0396.

A. (Sholly) The Task Force on Emergency Planning considered a number of possible rationales, including risk, probability, cost effectiveness, and the accident consequence spectrum. Following a review of these rationales, "The Task Force chose to base the rationale on a full spectrum of accidents and corresponding consequences tempered by probability considerations."[9/] The rationale used by the

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6/ Id. at 6.

7/ Id. at 18-23.

8/ Id. at 8.

9/ Id. at 15.

Task Force in establishing the EPZ planning distances is more fully described in Appendix 1 to NUREG-0396.

Q. Please describe the spectrum of accidents considered by the Task Force in NUREG-0396.

A. (Sholly) The Task Force on Emergency Planning considered a complete spectrum of accidents, including those discussed in environmental reports prepared by utilities as part of the operating license review (the so-called Class 1 through Class 8 accidents), accidents postulated for the purpose of evaluating plant design (design basis accidents in the Final Safety Analysis Report), and the spectrum of accidents identified in the WASH-1400 report. The Task Force concluded that the Class 1 through Class 8 accident discussions in environmental reports were too limited in scope and detail to be useful in emergency planning, and instead relied on design basis accidents and the WASH-1400 release categories. 10/

Q. Please describe specifically how the Surry Unit 1 results from WASH-1400 were used by the Task Force.

A. (Sholly) Concurrently with the operation of the Task Force, a report was being prepared for the NRC by Sandia Laboratories (now Sandia National Laboratories) which examined offsite emergency response measures for core melt accidents.

10/ *Id.* at 1-4.

This report, designated SAND78-0454, was published in June 1978.[11/] The Sandia report grouped the WASH-1400 release categories for Surry Unit 1 into "Melt-Through" and "Atmospheric" release groups (based on the location of containment failure identified for the WASH-1400 release categories).

Surry release categories PWR-1 through PWR-5 consist of accidents in which the containment was concluded to fail directly to the atmosphere as a result of structural failure or containment isolation failure. These release categories were grouped into the "Atmospheric Release" class. Surry release categories PWR-6 and PWR-7 consist of accidents in which the containment base was penetrated by core debris. These release categories were grouped into the "Melt-Through Release" class. The likelihood of the "Atmospheric" and "Melt-Through" classes were estimated by summing the probabilities of the contributing WASH-1400 release categories; "Atmospheric" releases were estimated to have a frequency of 1.4×10^{-5} per reactor-year, and "Melt-Through" releases were estimated to have a frequency of 4.6×10^{-5} per reactor-year.[12/]

11/ David C. Aldrich, Peter E. McGrath & Norman C. Rasmussen, Examination of Offsite Radiological Protective Measures for Nuclear Reactor Accidents Involving Core Melt, Sandia Laboratories, prepared for the U.S. Nuclear Regulatory Commission, SAND78-0454, June 1978 (hereinafter "SAND78-0454"). This report was reissued as NUREG/CR-1131 in October 1979 following the Three Mile Island accident.

12/ Id. at 43.

The characteristics of these release classes were then used as input to the WASH-1400 accident consequence code, referred to as CRAC (Calculation of Reactor Accident Consequences). The calculations were carried out using meteorological data from one reactor site and an assumed uniform population density of 100 persons per square mile.13/ The CRAC code calculations implemented for the Sandia study used hourly weather data for one year and 91 accident start times (a four day, thirteen-hour shift was assumed to take place for each start time; this results in each hour of the day being represented in 24 samples and a total of 91 samples are taken from one year's data).14/ The wind direction is assumed to be held constant during and following the release; other weather changes are modeled as indicated in the data.15/ A revised model of public evacuation (ultimately implemented in CRAC2, an improved version of the code) was also used.16/

The most frequently cited curve in NUREG-0396 which was derived from the Surry Unit 1 risk study results is a curve which plots the probability of whole-body dose versus

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13/ Id. at 36.

14/ According to a recent Brookhaven National Laboratory report, weather data from a typical year for New York City were used in calculations. See, W.T. Pratt & C. Hofmayer, et al., Technical Evaluation of the EPZ Sensitivity Study for Seabrook, Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, March 1987, page 6-2.

15/ Aldrich, et al., supra note 11, at 37-39..

16/ Id. at 59.

distance. (This curve, Figure 1-11 from NUREG-0396, is attached to this testimony as part of Table C). The curves on this figure were not calculated directly by the CRAC code, however. As explained in a recent Brookhaven National Laboratory (BNL) report, these curves were interpolated. BNL used the newer CRAC2 code to recalculate the dose vs. distance curves. The results of these calculations are shown in Table D, which is attached to this testimony (this calculation is only for the 200 rem whole-body curve).

Q. What results from the Sandia study were used in NUREG-0396?

A. (Sholly) NUREG-0396 contains a series of figures which are drawn from the Sandia report. These figures are Figures 1-11 through 1-18. These figures are reproduced as Table C, attached to this testimony.

VI. USE OF WASH-1400 INSIGHTS IN SETTING EPZ DISTANCES

Q. Please describe the insights from NUREG-0396, Figures 1-11 through 1-18, that were drawn by the Task Force on Emergency Planning.

A. (Sholly) The Task Force derived a number of insights from Figures 1-11 through 1-18. These insights were set forth in terms of the U.S. Environmental Protection Agency (EPA) "Protective Action Guide" (PAG) doses. PAGs are expressed in units of radiation dose (rem) which "represents trigger levels or initiation levels, which warrant pre-selected protective actions for the public if the projected (future) dose received by an individual in the absence of a protective action exceeds the PAG."[17] The EPA PAGs used by the Task Force were those for whole-body exposure and thyroid exposure. These PAGs have a range of 1-5 rem whole-body and 5-25 rem to the thyroid. According to EPA guidance, the lower dose in the PAG range is to be used if "there are no major local constraints in providing protection at that level, especially to sensitive populations." If local constraints make the lower value impractical to use, in no case should the higher value be exceeded in determining the need for protective action.[18]

Based on the figures, the Task Force concluded that given a core melt accident, there is about a 70% chance of exceeding the whole-body PAG doses at two miles, a 40% chance of exceeding the whole-body PAG doses at ten miles. Similarly, given a core melt accident, there is a near 100% chance of exceeding the 10-rem thyroid PAG dose at one mile, about an 80% chance at ten miles, and about a 40% chance at 25 miles. Based in significant part of these observations, the Task Force recommended that EPZs of 10 miles be established for the plume exposure pathway and 50 miles[19] for the injection exposure

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17/ Collins, et al., _supra_ note 3, at 3.

18/ Office of Radiation Programs, _Manual of Protective Action Guides and Protective Actions for Nuclear Incidents_, U.S. Environmental Protection Agency, EPA-520/1-75-001, September 1975, Revised June 1980, page 2.5.

19/ Collins, et al., _supra_ note 3, at 1-41 and 1-43.

pathway.[20/]

Q. Please describe how NUREG-0396 is related to the NRC's emergency planning regulations.

A. (Sholly) In October 1979, the Commission endorsed a policy of having a "conservative emergency planning policy in addition to the conservatism inherent in the defense-in-depth philosophy," and stated that a 10-mile plume EPZ and a 50-mile injection EPZ should be established around each nuclear power plant.[21/] Subsequently, these EPZs were codified in the NRC emergency planning rule when the final rule was adopted in 1980.[22/] Indeed, NUREG-0396 is explicitly referenced in the final rule.[23/]

NUREG-0654, which provides detailed guidance for the preparation and evaluation of radiological emergency plans for nuclear power plant accidents, also references the NUREG-0396 report. NUREG-0654 states that the 10-mile radius plume EPZ was based primarily on four considerations:[24/]

20/ Id. at 1-37, 1-41, and 1-43.

21/ Federal Register 61123, 23 October 1979.

22/ Federal Register 55402, 55406, 55411, 19 August 1980.

23/ 10 CFR Part 50, Appendix E, Section 1, fn 2.

24/ U.S. Nuclear Regulatory Commission and Federal Emergency Management Agency, 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, November 1980, page 12.

a. projected doses from the traditional design basis accidents would not exceed Protective Action Guide levels outside the zone;

b. projected doses from most core melt accidents would not exceed Protective Action Guide levels outside the zone;

c. for the worst core melt accidents, immediate life threatening doses would generally not occur outside the zone;

d. detailed planning within 10 miles would provide a substantial base for expansion of response efforts in the event that this proved necessary.

Quite clearly, two of these four considerations (i.e., considerations "b" and "c", above) are derived from the NUREG-0396 evaluation of doses from core melt accidents (which is based on the Surry analysis in WASH-1400). In addition, NUREG-0654 guidance on the timing and duration of releases and radiological characteristics of the releases is also derived from the NUREG-0396 evaluation of core melt accidents (which is based on the Surry analysis in WASH-1400).

VII. CONCLUSION REGARDING THE TECHNICAL BASES FOR EMERGENCY PLANNING

Q. What is your conclusion concerning the degree to which the NRC's emergency planning requirements are based on the analysis of Surry in WASH-1400?

A. (Sholly) It is evident, based on the above, that the current planning basis in NRC emergency planning regulations for nuclear power plants is substantially based on dose/distances insights derived from the risk assessment of

Surry performed in WASH-1400. Thus, the"spectrum of accidents" which were considered in establishing the EPZ distances in the NRC emergency planning rules explicitly included core melt accidents (up to and including those core melt accidents which were predicted to result in early containment failure and a large radiological release to the environment). A site-specific analysis which examines dose-distance relationships based on similar accidents would therefore provide useful information concerning the effectiveness of offsite emergency planning measures for the Seabrook site.

Q. Have you reviewed the release categories utilized by Dr. Jan Beyea in his calculations as set forth in his testimony in this proceeding?

A. (Sholly) Yes.

Q. Are the release categories utilized by Dr. Beyea consistent with the spectrum of releases utilized by the NRC in setting the technical basis for the emergency planning zones?

A. (Sholly) Yes, Dr. Beyea's release categories are very similar to the PWR-1 through PWR-9 release categories utilized in the NUREG-0396 report, which sets forth the technical basis for the NRC's emergency planning zones.

Q. Does this conclude your testimony?

A. (Sholly) Yes.

VIII. RADIATION RELEASES FROM REPRESENTATIVE ACCIDENTS WITHIN THE PLANNING SPECTRUM

Q. Dr. Beyea, before presenting the results of your calculations, describe in general terms how radioactive material is released to the environment and dispersed.

A. (Beyea) For a large release of radioactive material to occur following an accident, a "release pathway" from the reactor core to the environment is required. (See testimony of Steven Sholly.) One set of these pathways is generated by failure of the reactor's pressure vessel followed by failure of the containment building surrounding the vessel due to overpressurization. Researchers have outlined some, though not all, possible sequences and conditions for these failures.

Other pathways include releases occurring through a containment penetration system. Massive steam generator failure due to aging steam generator tubes might lead to a large release through the secondary cooling system. A so-called check-valve failure could connect the containment directly to the environment.

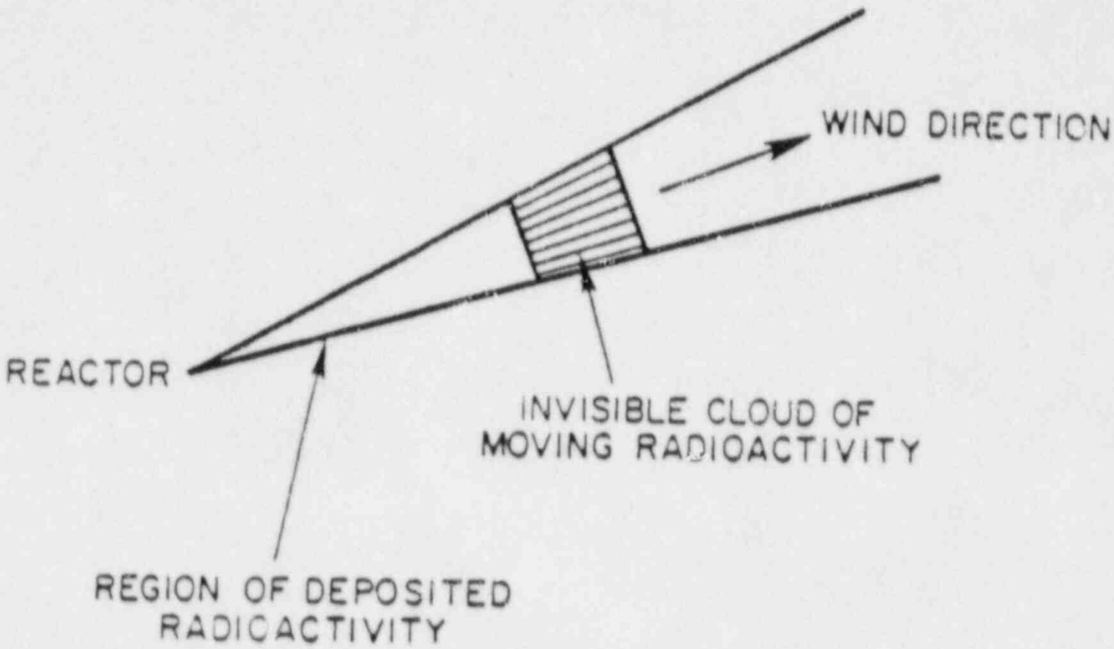
If a large release of radioactive material to the environment occurs, the material will leave the reactor as a "plume" of gases, aerosols and water droplets. Most of the large releases discussed in our testimony are assumed to occur over a period of thirty to sixty minutes; a few are assumed to take longer.

This escaping plume will rise to a height which is dependent on such variables as 1) the amount of heat released in the accident, 2) the weather condition existing at the time, and 3) whether or not the release takes place at the top or bottom of the structure. As will be shown later, there is no satisfactory formula that predicts the magnitude of plume rise.

The plume will be carried by the prevailing wind. Under the action of wind fluctuations and other weather conditions, the plume will spread in both the horizontal and vertical directions, so that the average concentration of radioactive material in the plume will decrease with time as it travels away from the reactor. (See Figure I). After a short time, the expanding edge of the plume will "touch" ground, and the non-gaseous radioactive aerosols will be dispersed along the ground, on vegetation, buildings, cars, people, etc. The rate at which material is removed from the plume, referred to as the deposition rate or "velocity", will also cause the concentration of material in the plume to decrease with time.

For the most energetic release categories, particularly the steam explosion categories which cause rapid rise of gases into the atmosphere, there is the possibility that escaping water vapor may condense to significant amounts of (radioactive) rain.

The plume may disperse radioactive material along the ground for more than a hundred miles if there is no reversal of wind direction. Much of the area where the plume has passed



TOP VIEW OF PLUME

FIGURE 1

will be contaminated for decades and "permanent" evacuation of the original population will be required there. In addition, as much as 10 percent of the material will be resuspended by the action of wind and blown about in succeeding weeks.[25/] The area of contamination will increase, causing residents who live outside the initial plume path to be exposed to radiation.

Immediately after the release, the plume will be visible, due to the escape of large amounts of cloud-forming water droplets. As the plume travels downwind and as the water droplets evaporate, the plume will most likely disappear from view, making it impossible for anyone without instruments to know where radioactivity is heading.

Q. How does the population receive radiation doses?

A. The population in the area under the plume would receive most radiation doses via three dose pathways.[26/]
(See Figure II):

1) From external radiation received directly from the radioactive plume itself. (In the

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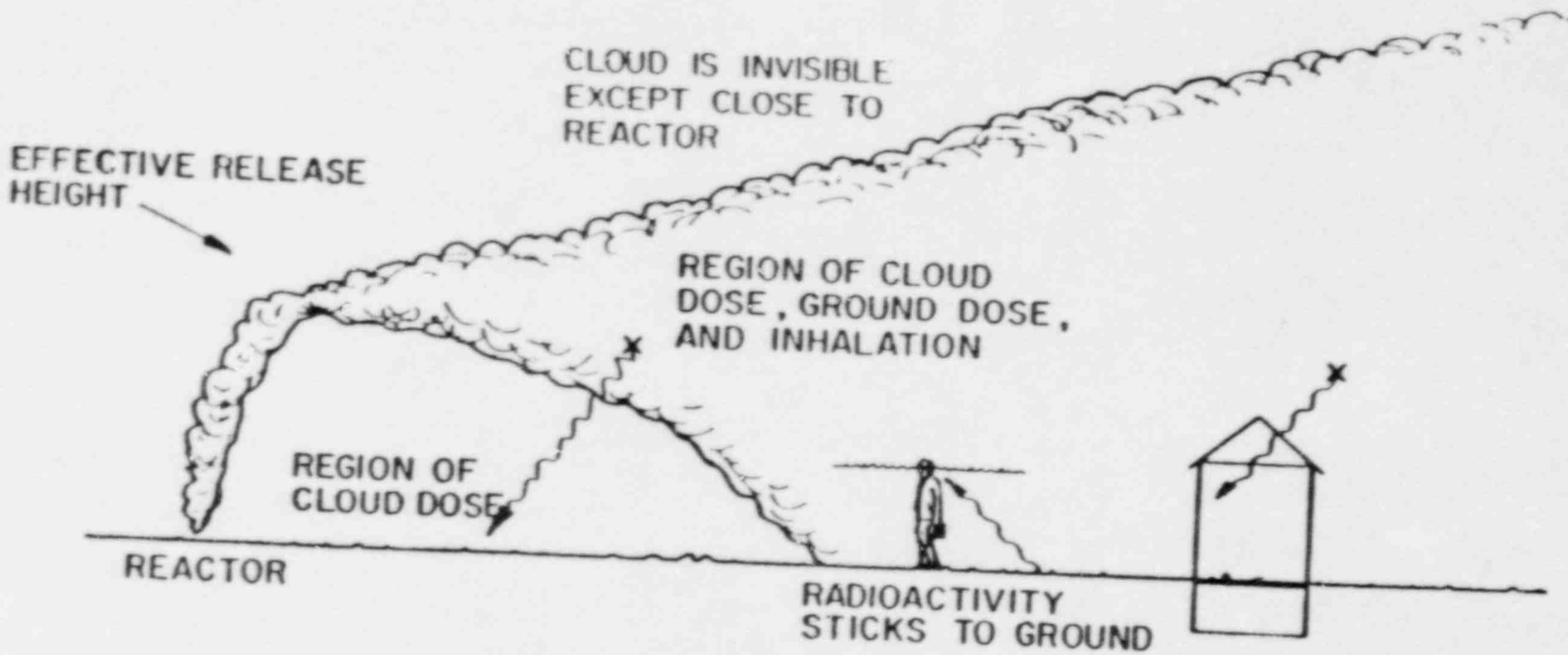
25/ U.S. Nuclear Regulatory Commission, Reactor Safety Study, (Washington, D.C., WASH-1400 or NUREG-75/014, 1975).

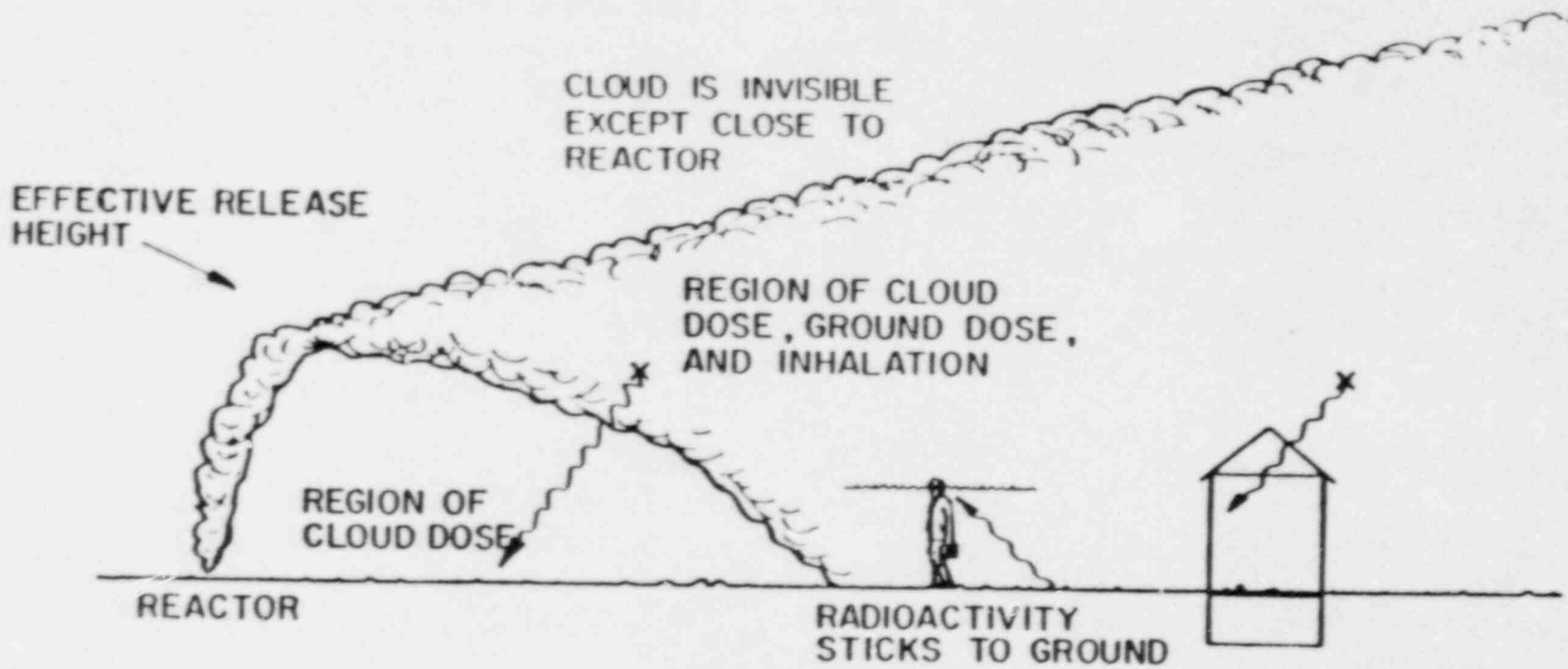
The Reactor Safety Study assumed a 50 percent retention rate for radioactivity deposited on vegetation. [See Appendices E and K] Although most of this loss is probably caused by subsequent rain, experimental data indicates that removal begins immediately after deposition. This initial loss must be due to wind action. Ten percent removal by wind seems a reasonable estimate.

26/ *See* Volume VI of WASH-1400, *supra*.



SIDE VIEW OF RADIOACTIVE PLUME

FIGURE II



SIDE VIEW OF RADIOACTIVE PLUME

FIGURE II

most serious accidents, the main part of the plume is projected to pass by very quickly, within one half to one hour, well before any significant evacuations of beach populations could occur.)

2) From radiation received following inhalation. The inhalation pathway would be the most important contributor to the thyroid dose. It could also be the major contributor to early health effects for accident sequences in which large quantities of ruthenium are released (PWR-1 type releases), i.e. steam explosion or high-pressure melt ejection.

3) From radiation received from material deposited on the ground or other surfaces (cars, skin etc.). It is this "ground dose" which would usually be the most important contributor to early fatalities because it would continue after the plume has passed. Even if evacuation is too slow to prevent inhalation of radiation, evacuation is still needed after the plume passes by to stop the accumulation of "ground dose"; the faster the evacuation, the lower the total "ground dose".

We have concentrated on these three pathways in our testimony, using standard methodology to calculate doses whenever possible. Because generic models do not consider beach situations, it was necessary to make special calculations for contributions to ground dose not normally considered in accident computer codes, but which are of special concern to unshielded beach populations. For instance, beach users caught in the plume would likely receive significant doses from radioactivity deposited on their skin and hair.

Other important dose pathways exist for persons not under the original plume. These include inhalation and ground dose from resuspended and redeposited radioactivity. (As has been stated earlier, as much as 10 percent of the plume's material may be resuspended within a few weeks.)[27/] Also of concern is radiation from contaminated vehicles and personal possessions brought to emergency reception centers. Finally, doses are also possible though ingestion of contaminated food or water.

Q. In what units are doses measured?

A. (Beyea) Doses to organs or to the whole body are measured in "rems," an indication of the amount of biologically-damaging energy absorbed by tissue or bone. The units are useful because a dose in rems can be used to project the likelihood that an exposed person will be injured.

27/ WASH-1400, supra.

Q. What are the dose levels that enter into your calculations?

A. (Beyea) The health consequences of radiation depend upon the magnitude of the dose received. Radiation doses to the whole body on the order of 100 rems or higher --doses that occur relatively close to the plant--may lead to immediate sickness (e.g., nausea) and "early death." At a dose of 125 rems for example, 50 percent of exposed persons would suffer from nausea.[28/]

Although not fatal by itself, nausea and vomiting should be considered in emergency planning--especially in estimating evacuation times. It is quite conceivable that outbreaks of nausea could preci[illegible]te panic in an evacuating population, thereby interfering with an orderly escape.

"Early death," a technical term in the radiological health field, refers to death within sixty days of exposure to a given dose. The threshold for early deaths is between 100 and 200 rems to the whole body, while the probability of early death increases with increasing dose and changes with "supportive" medical treatment.[29/] In accordance with standard practice,

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28/ See Volume VI of WASH-1400.

29/ In this proceeding, we do not testify as expert witnesses in the biological effects of radiation. Instead, we have relied on standard references to convert doses to health effects.

"Supportive" treatment is defined in the Reactor Safety Study Appendix VI, as such procedures as reverse isolation, sterilization of all objects in patient's room, use of laminar-air-flow systems, large doses of antibiotics, and transfusions of whole-blood packed cells or platelets.

we have taken 200 rem as a reference dose to indicate the onset of significant probability of early death.

Q. How have you modelled the plume movement and dose pathways?

A. (Beyea) The plume movement and the three major dose pathways[30/] discussed previously have been modelled by us in several computer programs. The programs have been checked against other consequence codes in use around the world.[31/] The original programs have been cited in other reports,[32/]

30/ The major sources of radiation that contribute to early death or delayed cancer are inhaled radioiodine, as well as external radiation (whole-body gamma) from the plume and from contaminated ground. In the case of PWR1 releases, there are situations where inhaled isotopes such as ruthenium can cause pulmonary syndrome, leading to early death.

31/ International Exercise in Consequence Modelling (Benchmark Study), sponsored by the Organization of Economic Cooperation and Development (O.E.C.D.), Nuclear Energy Agency, 38 Boulevard Suchet, 75016 Paris, France.

32/ Jan Beyea, Program BADAC-1, "Short-Term Doses Following a Hypothetical Core Meltdown (with Breach of Containment)" (1978), prepared for the New Jersey Department of Environmental Protection.

Jan Beyea and Frank von Hippel, "Some Long-Term Consequences of Hypothetical Major Releases of Radioactivity to the Atmosphere from Three Mile Island," report to the President's Council on Environmental Quality, Center for Environmental Studies, Princeton University, (1979), Appendix E.

A detailed discussion of the basic dose calculations used in these programs can be found in the Appendices of "A Study of the Consequences of Hypothetical Reactor Accidents at Barseback," Jan Beyea (Stockholm: Swedish Energy Commission, 1978).

(footnote continued)

while some modifications have been made for this study.[33] It was not necessary for these proceedings to use our most recent set of programs which directly include time-varying weather such as changing wind speed and changing turbulence. In the Seabrook beach case, doses are so high that these smaller probability events do not dominate the risk.

The dose to the population caught directly in the plume for the release categories under consideration has been calculated by these programs as a function of time after release for a range of weather conditions and for a range of model parameters. Ranges of model parameters were used because the appropriate values of parameters are currently uncertain.

The basic modelling used is similar to the approach taken by radiological protection agencies around the world, including the Nuclear Regulatory Commission and the New Hampshire Department of Public Health.[34]

(footnote continued)

Brian Palenik and Jan Beyea, "Some Consequences of Catastrophic Accidents at Indian Point and Their Implications for Emergency Planning," direct testimony on behalf of New York State Attorney General, Union of Concerned Scientists (UCS), New York Public Interest Research Group (NYPIRG), New York City Audubon Society, before NRC Atomic Safety and Licensing Board, July, 1982.

33/ For this study, we have used appropriate dose scaling factors, as discussed in detail later, to include dose contributions from material deposited directly on the cars and skin of evacuees.

34/ D.V. Pergola, R.B Harvey, Jr., J.G. Parillo, "SB Metpac, A Computer Software Package Which Evaluates the Consequences of an Off-Site Radioactive Release Written for the Seabrook Station Site at Seabrook, New Hampshire" (Yankee Atomic Electric Company, Framingham, Mass., May 1986).

The only specialized aspects of our calculations involve the following:

1) Radiation shielding: Radiation shielding factors for cars used in the 1975 Reactor Safety Study have been updated to account for changes in car construction that have been made to improve fuel economy in the intervening years.

2) Accounting for dispersion over water. Certain beach sites, like Seabrook, have water between them and the reactor. We have made adjustments for decreased dispersion using standard methodology.[35/]

3) Radioactivity deposited on vehicle surfaces: In some of our calculations, we have accounted for radioactivity that would be deposited on cars caught in the plume. This radioactivity could cause a significant dose to riders and should not be ignored.

4) Radioactivity deposited on the skin and clothing of beach-goers: In some of our calculations, we have accounted for radioactivity that would be deposited on beach occupants while standing either on the beach, in parking lots, or outside their cars waiting for traffic to move. Although not generally a major

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35/ In such a case (Seabrook Beach), we have shifted dispersion parameters by one stability class. See footnote 39.

effect to be considered at other sites, we have found that the dose from skin contamination is significant at Seabrook because of the large beach population that could be caught outdoors.

Because doses from contaminated skin and vehicles have not to our knowledge been considered in past consequence modelling, our calculations have been presented with and without their inclusion. Their impact is to increase, in comparison to other sites, the number of meteorological conditions during which early death would occur.

Q. In what ways have your calculations taken into account the uncertainties in the current state of consequence modelling?

A. (Beyea)

Plume Rise

The treatment of plume rise due to thermal buoyancy illustrates the current uncertainty that exists in dose calculations due to inadequate knowledge of model parameters. Since calculated doses can be very sensitive to whether or not the edge of the plume has "touched" ground, knowledge of the initial rise of the plume can be critical for projecting doses. Yet, lack of understanding, both experimental and theoretical, about plume rise makes prediction of this parameter difficult.

Figure III shows the enormous range in airborne concentration of radioactivity (and therefore inhalation and ground doses) predicted for the same release of radioactivity by modellers from different countries under one set of weather conditions.[36/] Most of this range arises because of different predictions of plume rise. These results from the international exercise in consequence modelling demonstrate that dose predictions from a particular computer code may be highly uncertain within about 20 miles from the reactor if based on one set of model parameters. (Output from the computer codes used to develop our testimony were included in this consequence modelling exercise.)

If a range of weather conditions is examined, the range of doses predicted by different computer codes shows much less of a spread. It is for this reason that we considered a range of weather conditions in this study rather than relying exclusively on predictions using one set of model parameters. The dose ranges used in our testimony fall well within the full range given in Figure III.

At Seabrook, plume rise is a critical issue only for the PWR1-type releases. The other releases are not characterized by sufficient thermal bouyancy to make it an issue.

36/ Figure III has been taken from S. Vogt, CNSI Benchmark Study of Consequence Models, International Comparison of Models Established for the Calculation of Consequences of Accidents in Reactor Risk Studies, Comparison of Results Concerning Problem 1. SINDOC(81) 43.

FIGURE III. RANGE OF AIR CONCENTRATIONS OF RADIOACTIVITY PREDICTED BY DIFFERENT MODELLERS FOR THE SAME RELEASE SCENARIO. (MOST OF THE VARIATION IS DUE TO VARIATION IN THE TREATMENT OF PLUME RISE.)

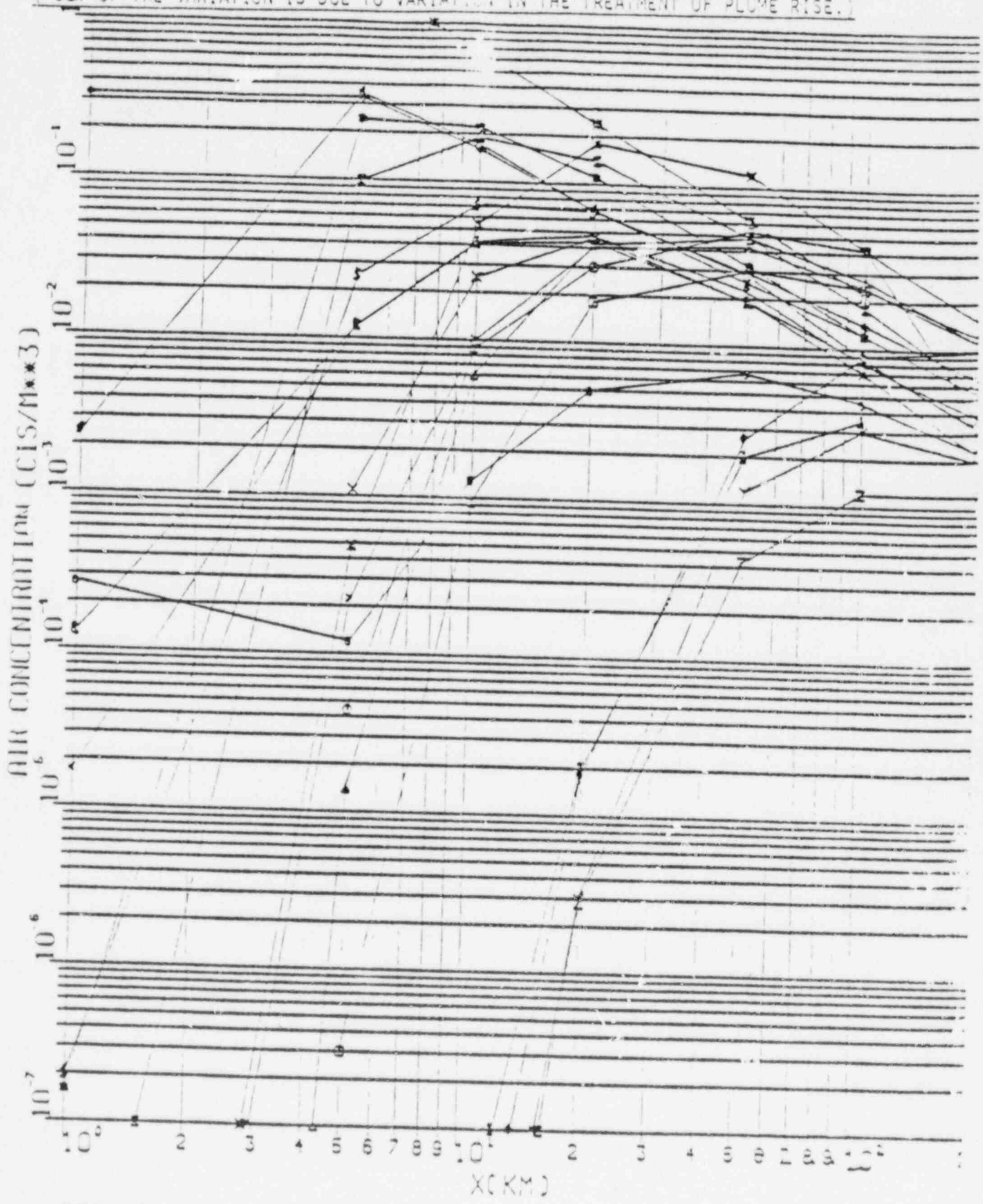

ABB. 21 : BENCHMARK PROBLEM 1

INTEGRATED AIR CONCENTRATION (CIS/M**3)

BMP2 D STABILITY NO RAIN

Deposition Velocity

A range of deposition velocities has not been examined in this testimony. (Deposition velocity governs the rate at which radioactive material deposits on surfaces). Like plume rise, this parameter is also uncertain, but does not have a critical impact on any of our calculations. For simplicity we have used a mid-range value of 1 cm/sec.[37/]

Sea Breezes

Because of the complexity involved in modelling sea breezes, we have treated them qualitatively. To obtain an understanding of the sea breeze phenomenon, it is useful to begin with a simple case, where the inland wind speed is very low. A circulating cell structure would result from daytime heating of the land, extending many miles over both land and water.[38/]

In this example, the wind would blow toward the reactor away from the beach, yet radioactivity would still reach the beach for either low-rising or high-rising plumes, as radioactivity became entrained in the cell and circulated within it. However, in this scenario, because it would take several hours for the radioactivity to reach the beach, it is

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37/ A complete discussion of this parameter can be found in the Barseback Study, supra.

38/ C.S. Keen, "Sea Breezes in the Complex Terrain of the Cape Peninsula," in Third Conference Meteorology of the Coastal Zone (American Meteorological Society, Boston, Mass., January 1984, pp. 129-134).

not possible to say, without detailed study, whether or not the radioactivity would arrive before the beach goers had left.[39/]

In many other sea-breeze cases, the inland wind would be too strong to ignore. The resulting structures can be very complex, either causing plumes to rise above the beach and reduce doses or to slow plumes down, producing higher doses. If the inland wind is very strong, it will eliminate the cell structure entirely or drive it offshore.

In general, turbulence at the beach should increase under sea breeze conditions, leading to the possibility that above-ground plumes will be brought quickly to the ground (fumigated) once the region of excess turbulence has been reached.

The possibility must be considered that a moisture-laden plume could produce its own rain, following rapid mixture with cold, turbulent sea air that would be filled with salt particles capable of nucleating water droplets. Rain would be

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39/ W.A. Lyons, "Lectures on Air Pollution and Environmental Impact Analysis," American Meteorological Society, Boston, Mass., 1975. See also, S.J. Mass and P.R. Harrison, "Dispersion Over Water: A Case Study of a Non-Buoyant Plume in the Santa Barbara Channel, California," in Joint Conference on Applications of Air Pollution Meteorology, Nov. 29-Dec. 2, 1977 (American Meteorological Society, Boston, Mass., pp. 12-15). See also, S. Barr, W.E. Clements, "Diffusion Modeling: Principles of Application," in Atmospheric Science and Power Production, (Report DOE/TIC-27601, Department of Energy, Washington, D.C., 1984, p. 613).

extremely serious for the beach goers, because unusually large amounts of radioactivity would be carried to ground level along with the drops.

In considering the various meteorological combinations that could occur, it is possible to find some conditions that increase doses at the beach and some conditions that decrease doses--sometime during the course of the same day.

In light of this variation, we have assumed that our calculations without sea breeze effects represent a mid-range case.

Q. What are the characteristics of the release types you have considered and why have you chosen to use them?

A. (Beyea) Because the number of possible accident sequences is very large, it would be prohibitive to perform consequence calculations for every possibility. Instead, following standard practice, we have picked surrogate release categories that are intended to span the range of possibilities. As mentioned in the summary, releases have been chosen that generally fall into the release categories used in NUREG-0396, but which take into account site-specific differences. The basic reference documents utilized relating to site-specific accident sequences at the Seabrook Plant are 1) the Licensee's Seabrook Probabilistic Safety Assessment (PSA),[40/] and the review of the PSA carried out by analysts

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40/ Pickard, Lowe and Garrick, Seabrook Station Probabilistic Safety Assessment, 6 volumes, December, 1983.

at Brookhaven National Laboratories for the NRC.[41/]

In our study, we have generally accepted the Brookhaven recommendations, although for completeness we have considered some PSA categories without modification. In such cases, we have included them as part of our generic release categories.

In the release categories used for our testimony, we have picked one specific sequence to define the release magnitude for each category. However, it is important to bear in mind that the probability of the category is not the probability of the specific accident analyzed. The true probability is the sum of the probabilities of all accident sequences, known or unknown, that have similar release magnitudes.

1. Category 1 (PWR1-type): Early Containment Failure with Core Oxidation. This category is represented by an "S1" sequence as defined in the Seabrook (PSA). Also included in this category is a high-pressure melt ejection sequence.

One of the questions raised by the Brookhaven review of the PSA concerns the assumed rate at which heat would be released during an accident--a variable which governs plume rise. The PSA assumes uniformly high values. In particular, for the S1 case, the PSA assumes such a high release of thermal energy that the plume passes high overhead, causing relatively low doses to the beach population, according to

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41/ M. Khatib-Rahbar, A.K. Agrawal, H. Ludewig, W.T. Pratt, "A Review of the Seabrook Station Probabilistic Safety Assessment: Containment Failure Modes and Radiological Source Term," Brookhaven National Laboratory, Upton, Long Island, prepared for U.S. NRC, draft, September, 1985.

U.S. Nuclear Regulatory Commission, Reactor Safety Study, (Washington, D.C., WASH-1400 or NUREG-75/014, 1975).

conventional consequence models. As indicated by Gordon Thompson (at p. 76 infra) it will not be possible to resolve this discrepancy since a large range of heat rates is possible, depending on the dynamics of the accident. Because the Brookhaven assumption on heat rates represents a mid-range value in the spectrum found by Thompson, we have used it in our calculations of doses from S1 releases, recognizing that the actual doses could be significantly higher or lower.

2. Category 2 (PWR2-type): Severe Containment Bypass. We include in this category an "S6V-total" sequence as defined by analysts at Brookhaven. In this release category, a direct pathway to the atmosphere is opened as a result of containment bypass. 43% of radioiodine, 43% of radiocesium, and 40% of radiotellurium in the core are projected to escape.

In addition to the "interfacing systems accidents" used to define this accident in the PSA, we include in this category thermally-induced steam generator tube failures.

We also specifically analyze the PWR2 release overpressurization scenario utilized in the Reactor Safety Study and NUREG-0396. Note that this release category is generally similar to the preceding rapid bypass category represented by S6V-total.

3. Category 3 (PWR3-type) Slow Containment Bypass. The Seabrook PSA modelled a containment bypass release as a "puff" release in which radioactivity is assumed to escape at different times, for periods of varying duration. We refer to this release category in the Tables with the notation used in the PSA to label the first and most dangerous puff (S6V-1).

Brookhaven, in its review of the PSA assumed radioactivity would be assumed to escape over a period of one hour. For our testimony, we have made consequence calculations using both sets of assumptions. S6V-total in Category 2 represents the Brookhaven approach; S6V-1 in Category 3 represents that taken in the PSA.

4. Category 4: (PWR4-PWR9 -types) The less severe accidents utilized in NUREG-0396 are grouped in this category. Although such accidents can cause doses in excess of protective action guidelines and can increase delayed cancer risks in exposed populations, they are not generally projected to lead to early health affects.

A summary of the characteristics of the first three release categories is given in Table 1.

Q. What special characteristics around Seabrook affect the consequences of a release there?

A. (Beyea) Our investigation of the consequences of releases of radioactivity at Seabrook concentrates on the summer months. The potential consequences, especially with respect to early death from a serious accident at the Seabrook plant, increase greatly during these months due to a large summer population in the area. These summer residents, day visitors, etc. increase the exposed population, and by increasing the evacuation time necessary to clear the area, they increase the potential time exposure. Furthermore, the consequences to a beach area population may be greater than the consequences to an inland population under similar conditions due to a lack of shielding normally provided by buildings. The addition of increased consequences due to material deposited directly on the skin of a beach population must also be considered for the Seabrook plant. Taken together, these factors make summer release scenarios at Seabrook worthy of

TABLE 1

RELEASE PARAMETERS

	PWR1	PWR2		PWR[illegible]
	S1 Steam Explosion	S6V-total Containment Bypass	RSS Over-Pressurization	S6V-1 Containment Bypass
Warning Time	0.3	1.0	1.0	1.7
Release Duration (hrs)	0.5	1.0	0.5	1.0
Release Time (hrs)	1.4	2.5	2.5	2.2
Energy Release Rate (million BTU/hr)	520	low*	170	low*
Plume Rise (m)**	200-850	30	80-300	30
Release Fractions				
Noble Gases	.94	.97	0.90	.15
Iodine	.75	.43	0.7	.11
Cesium	.75	.43	0.5	.11
Telurium	.39	.40	0.3	.02
Barium	.093	.048	0.06	.014
Ruthenium	.46	.033	0.02	.0041
Lanthanides	.0028	.0053	0.004	.00041

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* Brookhaven suggests a much lower release ratio than does the Seabrook PSA. However, the plume rise is low in both cases.

**Calculations for stability classes A-E. Plume rise varies within [illegible] because of different wind speeds. Variations for S6V releases are [illegible] they can be ignored. For an S1 release, the following values apply:

Stability Class	Wind Speed 2 m/sec	4 m/sec	8 m/sec
A-D	850 m	440 m	230 m
E	350	280	230

special consideration, and we have included them in our investigation of the potential consequences of accidents at Seabrook.

Figure IV shows the location of the Seabrook beaches.

It should be noted that for the most severe accident categories considered, as will be discussed below, doses are so far above threshold for overcast conditions, that early deaths are possible at any time of the year. Nevertheless, the number of people who would die would increase greatly during the summer. Furthermore, intermediate accidents--those that would usually not cause early deaths--would be expected to cause early deaths at the beaches. In other words, during the summer, there is a much wider spectrum of accidents that can cause early fatalities.

Q. What are the assumptions behind the evacuation times you have used?

A. (Beyea) At some point during the operation of a reactor, the nuclear facility operator (NFO) may notify the appropriate state and local officials of an "unusual event," an occurrence that may lead to an eventual release of radioactivity. Depending on the seriousness of the event or of following events, a higher emergency level may be reached. The NFO may eventually recommend, in consultation with officials and technical support staff, that an evacuation is necessary of all or part of the surrounding population. The appropriate

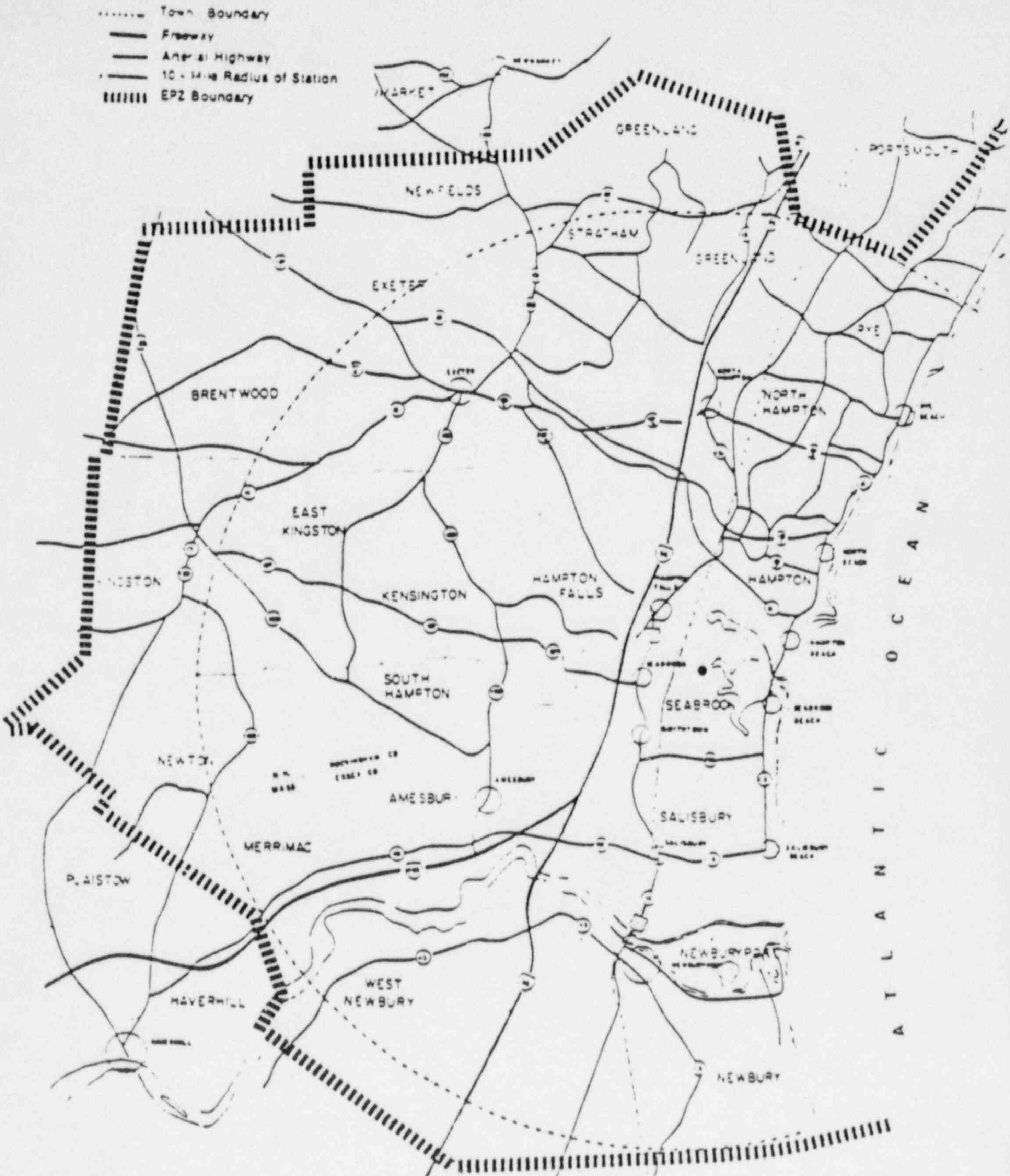

FIGURE IV: SEABROOK AND AREA BEACHES

local officials, who may or may not have received prior warning, are then notified, and the emergency warning system will presumably be activated as soon as possible.

Time elapses between an initial indication to the operator and the moment state and local officials begin notification of the population. CONSAD (a consulting firm to FEMA) estimated this time to take 19-78 minutes during the day and 50 minutes at night. 42/ Their review of historical data shows these kinds of estimates can range from one to many hours for a range of natural disasters and false alerts. Our work here assumes 45 minutes. In addition, some time will be needed to actually notify the population that an evacuation is needed. We take 15 minutes for this time, so that evacuation is assumed to begin one hour (45 plus 15 minutes) after the decision is made to evacuate.

We also assume that the NFO receives an indication of a pending release before the release. This warning time is taken as 18 minutes for a steam explosion, one hour for a rapid containment bypass (S6V-total), one hour for a PWR-2 release, and 1.7 hours for a slow containment bypass (S6V-1). These are the assumptions made by the analysts (Brookhaven, Seabrook PSA, Reactor Safety Study) who devised the release categories

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42/ CONSAD Research Corporation, "An Assessment of Evacuation Time Around the Indian Point Nuclear Power Station," June 20, 1980; revised June 23, 1980, p. 2.7-2.9.

studied. When the one hour delay involved in starting the actual evacuation is accounted for, the results are as follows.

Steam explosion: evacuation starts 42 minutes after radioactivity begins escaping.

PWR-2 and rapid containment bypass (S6V-total): evacuation starts at the same time as radioactivity begins to escape.

Slow containment bypass (S6V-1): Evacuation starts 42 minutes before radioactivity begins to escape.

The evacuation time estimates themselves are based on assumptions about conditions during the evacuation, the state of readiness of an evacuation system, etc. These assumptions vary, leading to differences in evacuation times. The evacuation times for five earlier studies of a Seabrook area evacuation are listed in Table 2. Some of the evacuation times in the table for a two mile radius (and five mile radius) appear to be for a selective evacuation from within that radius. We have used five hours as a representative estimate for beach site evacuation.

Current emergency plans at Seabrook call for notification of beach populations at an earlier stage in an accident than for the general population. However, for PWR1-PWR3 categories, there is doubt as to how much time would actually be gained by this procedural modification. Although we have not taken credit for extra warning time to the beach population, our results can be easily modified to do so. It is only necessary to relabel the evacuation time assigned to our tables. In

TABLE 2

<u>SEABROOK EVACUATION CLEAR TIME ESTIMATES</u>[a)]

SUMMER DAY SCENARIO

RADIUS	DEGREES	HMM[b)]	Vorhees[c)]	Maguire[d)]	NRC[e)]	KLD[f)]
0-2	360	4:50	5:10	[illegible]	----	4:40
0-3	180 East	5:20	----	----	----	----
0-5	360	5:50	5:10-5:40	----	----	6:20
0-10	360	6:05	5:10-6:10	[illegible]0	11:25	6:40

a) Time (Hours:minutes) for the population to clear the indicated area after notification.

b) "Preliminary Evacuation Clear Time Estimates for Areas Near Seabrook Station," HMM Document No. C-80-024A, HMM Associates, Inc., May [illegible] 1980.

c) "Final Report, Estimate of Evacuation Times," Alan M. Vorhees & Associates, July 1980.

d) "Emergency Planning Zone Evacuation Clear Time Estimates" C.E. Maquire, Inc., February 1983.

e) "An Independent Assessment of Evacuation Time Estimates for a Peak Population Scenario in the Emergency Planning Zone of the Seabrook Nuclear Power Station," M.P. Mueller, et al, Pacific Northwest Laboratory. NUREG/CR-2903 PNL-4290.

f) "Evacuation Plan Update, Progress Report No. 3," KLD Associates, [illegible] Broadway, Huntington Station, NY 11746, Januaray 20, 198[illegible], Table 19, Scenario 1A. These calculations refer to the beach population, but assume the entire five mile population is evacuated officially and that 2[illegible] of the population beyond five miles evacuates spontaneously. It is further assumed that beaches are at 80% of capacity and that officials attempt to notify the beach population at the Site Alert stage, [illegible] minutes <u>before</u> a General Site emergency is called. To make these estimates consistent with the assumptions used in our calculations, [illegible] minutes should be added to the numbers shown. On the other hand, [illegible] minutes should be subtracted to avoid double counting the delay associated with notifying beach occupants, which is already included in the KLD time estimates.

other words, if beach populations are assumed to begin evacuating 15-minutes earlier than normal, the equivalent evacuation time in our calculations would be 5 hours minus 15 minutes, not 5 hours.

According to testimony by Thomas Adler in this proceeding, actual evacuation times from the contaminated area would be much, much longer. Some of the persons exposed in an accident will therefore likely receive larger doses than presented in our tables. Our tables, therefore, lead to conservative estimates of the numbers of persons exposed to possible early death.

Q. Is the population around Seabrook subjected to possible "early death" for releases during the summer?

A. (Beyea) We have investigated the conditions under which the nearest beach population, at 2 miles and 4 miles, might be exposed to doses at a threshold level for early death (200 rem) for the release categories discussed previously. According to standard references (see Moeller, et al.)[43/] At 200 rem, a few percent of exposed persons would die within a two month period, a few percent of women under 40 would be

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43/ J.S. Evans, D.W. Moeller, D.W. Cooper, "Health Effects Model for Nuclear Power Plant Accident Consequences Analyses," (U.S. Nuclear Regulatory Commission, Washington, D.C., NUREG/CR-4214, 1985) The "LD50" for nausea is given as 1.4 Gy in Table 1.3, page II-29. 1.4 Gy equals about 125 rem.

Biological Effects of Ionizing Radiation, National Academy of Sciences, Washington, D.C., 1980.

permanently sterilized, and a few percent more would develop cataracts. Table 3 illustrates some of our findings for 2 miles. Weather stability class, wind speed, and the time it would take for the beach population ' , receive a 200 rem dose under those conditions are listed.

We have found these estimates for two sets of assumptions. The first set assumes that all the population is inside cars when the release occurs so that skin and clothes do not get contaminated. Doses are also reduced because of the partial shielding provided by the car from the radioactivity on the ground. The fractional decrease in dose from shielding, here referred to as a 'dose scaling factor", is calculated to be .53-.78 for this set of assumptions. The time it takes for a person in a car waiting within the plume to receive a 200 rem dose is then listed in the table. We assume that vehicles remain stalled in traffic within contaminated ground and then move rapidly out of the area once the roads are cleared at the end of five hours. We also assume that a person once evacuated receives no additional dose once outside the plume path.

On the basis of our consideration of a Seabrook-type evacuation, we have decided to also use a second set of assumptions. Some of the population will not have reached their vehicles before plume passage. (Maguire, for example, assumes up to an hour for the beach population to "mobilize"

TABLE 3

EXPOSURE OF 2-MILE BEACH POPULATION[a]
TO RISK OF EARLY DEATH ON A SUMMER DAY
(SKIN AND CAR DEPOSITION NOT INCLUDED)

Stab-[c] ility Class	Wind Speed (m/sec)	Time in Hours to Reach[b] 200 Rem: PWR1 $\overline{SI}$[e]	PWR2 S6V-Total	PWR3 S6V-1	Risk of Early Death?[d] $\overline{SI}$[e]	S6V-tot.	S6V-1
A	2	14. -21	18. ->24	>24	50% chance	N	N
A	4	20. ->24	>24	>24	"	N	N
A	8	>24	>24	>24	"	N	N
B	2	>24	5. -7	>24	"	Y	N
B	4	9.5-14	13. -19	>24	"	N	N
B	8	14. -21	>24	>24	"	N	N
C	2	>24	<1	19. -24	"	Y	N
C	4	>24	2.6- 3.7	>24	"	Y	N
C	8	7.7-12	8.3-12	>24	"	N	N
D	2	>24	<1	5. -7.0	25% chance	Y	Y
D	4	>24	<1	12. -17	"	Y	N
D	8	>24	1. - 1.5	>24	"	Y	N

a) The population two miles from the plant, but not directly across the lagoon. Times would be shorter for populations with water between them and the reactor due to reduced dispersions.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. Ground shielding factors are assumed to range from 0.53 to 0.78, depending on the type of automobile. See Question 13 for further details.
c) Pasquill stability class.
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) If the plume rises high, as at Chernobyl, the population will be protected against early death for this release. Otherwise, the population will be exposed to risk of early death. (Both the thermal release rate and the plume rise equation are uncertain. See text of question 12 for discussion of probabilities in table.)

itself for an evacuation.)[44] Of those that do reach their vehicles before plume passage, some will leave their windows open and some will not enter their cars until traffic starts to move. Thus, some of the population will have radioactive material deposited directly on their skin and hair. We refer to the dose from this material as a "skin deposition" dose. Similarly, we take into account material deposited directly on cars in the plume and the dose resulting from this material (a "car deposition" dose).

For this second set of assumptions, we have estimated that the dose to a person shielded by a car, but exposed to both skin deposition and car deposition doses, would be 1.0 to 1.3 times the dose to an unshielded person exposed to a plane of contaminated ground (see below). The dose scaling factor range is thus 1.0-1.3. Results using this range are shown in Table 4.

A great deal of information is contained in Tables 3, 4 and similar Tables to be presented later. Consider, for example, D-stability conditions. Note that the times shown refer to "clearing" time, that is the time for the last person in the area to be evacuated. But even a 1-hour evacuation time, which might apply to the earliest evacuees, is insufficient to keep

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44/ C.E. Maguire, Inc., "Emergency Planning Zone Evacuation Clear Time Estimates," February 1983.

TABLE 4

EXPOSURE OF 2-MILE BEACH POPULATION[a)] TO RISK OF EARLY DEATH ON A SUMMER DAY
INCLUDES DOSE FROM SKIN & CAR DEPOSITION

Stab-[c)] ility Class	Wind Speed (m/sec)	Time in Hours to Reach[b)] 200 Rem: PWR1 $\overline{S1}$[e)]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d)] $\overline{S1}$[e)]	S6V-tot.	S6V-1
A	2	8.2-11	11-14	>24	50% chance	N	N
A	4	12. -15	>24	>24	"	N	N
A	8	>24	>24	>24	"	N	N
B	2	19. -24	3.1-4	>24	"	Y	N
B	4	5.5-7.3	7.8-10	>24	"	N?	N
B	8	8.4-11	17.4-23	>24	"	N	N
C	2	>24	<1	12. -15	"	Y	N
C	4	>24	1.7-2	>24	"	Y	N
C	8	4.4-5.9	5 -6.5	>24	"	Y	N
D	2	>24	<1	3.5-4.2	25% chance	Y	Y
D	4	>24	<1	7.6-9.6	"	Y	N?
D	8	>24	<1	17.4-22.5	"	Y	N

a) The population two miles from the plant, but not directly across the lagoon. Times would be shorter for populations with water between them and the reactor due to reduced dispersions.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car and directly on the individual. The effective ground shielding factors range from 1.0 to 1.3, depending on the type of automobile. See Question 13 for further details.
c) Pasquill stability class.
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) If the plume rises high, as at Chernobyl, the population will be protected against early death for this release. Otherwise, the population will be exposed to risk of early death. (Both the thermal release rate and the plume rise equation are uncertain. See text of question 12 for discussion of probabilities in table.)

doses below 200 rem for an S6V-Total release. On the other hand, the first of the evacuees to leave during an S6V-1 release would escape a 200-rem dose.

If the time to reach a 200-rem dose shown in the tables is compared with a 5-hour evacuation time, one arrives at a "yes/no" indication of whether or not the population at 2 miles is exposed to risk of early death. This is noted in the last set of columns in each table.

Some of the entries are marked with a question mark. A question mark indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached early in the evacuation. In such cases, a 5-hour evacuation time calculated from traffic models may be optimistic. Because we were unable to determine a quantitative estimate of the likely delay in evacuation that would result from cases of nausea, we have not been able to do more than indicate uncertainty.

Note that no entries are shown in the Tables for a PWR-2 release. The results turned out to be so similar to, or worse than, the SV6-total release that it was not necessary to include separate entries.

Several caveats about the tables should be kept in mind, especially when exposure of the population is indicated. First of all, risk of early death is much higher for persons very close to the plant where doses reach high levels very rapidly.

Second, we have not looked at slower wind speeds for the various stability classes nor have we examined changing weather conditions. Both of these situations can lead to higher doses. Thus, Tables 3 and 4 do not include the worst possible weather conditions but only the most probable.

A third caveat is that, while D conditions generally represent overcast days, we have not looked at actual precipitation conditions that sometimes catch populations on the beach. The time for a dose to reach 200 rem is greatly decreased in this case (for the same wind speed) due to the increased deposition of radioactive material. Evacuation time is also increased.

On the other hand, overcast conditions in the morning would deter people from coming to the beach. The lower populations would mean reduced clear time estimates. Recall, however, that there is a multi-hour underestimate of clear times in our work for most of the beaches (see Adler). In any case, doses tend to be so high under D-conditions for the S6-V total release that reduced clear times are insufficient to provide protection. The same is true for the S1 release for low thermal release rates and low plumes rise.

Finally, it should be emphasized that the population's exposure may be increased if the shown evacuation times are, for whatever reason, longer than assumed here.

In any case, the results of Tables 3 and 4 can be combined with weather frequency data (Table 15) to show that for the S6V-total release which represents the severe-containment-bypass categories, if the 2-mile beach population is downwind, it will be exposed to risk of early death under meteorological conditions that would be expected to occur about 70-75% of the time.

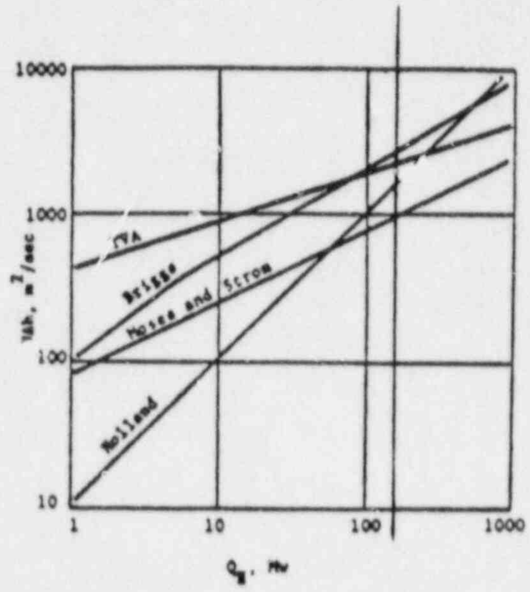
In contrast, the results in Tables 3 and 4 for the slow-containment-bypass release, S6V-1, indicate that the population at 2 miles is generally not exposed to early death for this release.

Surprisingly, the S1-steam-explosion release, which represents the largest release of all, in some circumstances might causes fewer problems for the beach population at 2 miles than the PWR-3 type release. The reason for this is that the projected plume rise may be so great, as occurred at Chernobyl, that the plume passes high over the nearby populations. We estimate a 50-percent chance that this will be the case for A, B and C stability conditions and a 75-percent chance during D conditions. Our rationale is that the height to which any radioactive plume rises is uncertain, as was discussed earlier. Should the true plume ris e a factor of two less than the mid-range value predicted by standard plume rise formulas, which is within the range of uncertainty (see Fig. 5), early

Figure 5

VARIATION IN PLUME RISE

ACCORDING TO SOME WELL-KNOWN FORMULAS



The vertical line at Q_h=150 megawatts corresponds to an $\overline{SI}$ release. At this heat rate, the spread in predictions made by different formula is about a factor of two.

The graph has been taken from G.A. Briggs, "Plume Rise Predictions" in Lectures on Air Pollution and Environmental Impact Analyses, American Meteorological Society, 45 Beacon Street, Boston, Mass. 02108 U.S.A., 1975.

We quote from page 60: "It is no wonder that so many plume rise formulas have been developed. What is particularly distressing is the degree to which they diverge on predicting Δh for a given source and given conditions."

deaths from external gamma exposures become frequent for A, B, and C stability classes. It should also be borne in mind that the PWR-1 releases are projected to include copious amounts of isotopes that can give high lung doses. Thus, 1-day lung dose can contribute to early death when whole body dose is below 200 rem.

When these factors are all included, the combined uncertainty is so broad that it is a toss up (50%) as to whether or not early deaths would occur following an S1 release for A, B, and C stability classes. As for D-stability class, two independent events must conspire to produce early deaths: both the heat rate must be low and a low plume rise formula must be correct. As a result, we estimate that there is a 25% chance that doses will exceed 200 rem to the whole body or the equivalent 1-day lung dose under D-stability class for this release.

It should also be recognized that a real accident may be less severe than the S1-case assumes. Paradoxically, because of lower plume rise, a small breach of containment following a steam explosion could be more severe than a large breach as far as nearby populations are concerned.

Finally, it should be borne in mind that turbulent interaction with the sea breeze and/or condensation of radioactive rain could bring radioactivity down to ground level. An enormous amount of radioactivity would be passing overhead; even a relatively weak meteorological process, one normally not considered in reactor accident dispersion modelling, could couple the upper air with air at ground level, causing high doses.

Note that we have not shown results for release classes PWR4 through PWR9. Although these releases can cause doses in excess of protective action guides, they rarely lead to doses in excess of 200 rem. Doses for those categories are dominated by noble gases, so that ground deposition can be ignored. As a result, the dose ends after plume passage. Without effective sheltering, the only emergency measure that has any impact on doses for these release classes is pre-plume evacuation.

IX. RADIATION DOSES FROM REPRESENTATIVE ACCIDENTS WITHIN THE PLANNING SPECTRUM

Q. How were your dose scaling factors obtained?

A. (Beyea) The basic dose scaling factor, with car and skin deposition ignored, was calculated to have a range of 0.53-0.78, assuming that an evacuee is inside a car in the plume deposition area. This range represents an updating of the 0.4-7 shielding factor range used in the Reactor Safety Study (WASH-1400). Cars are lighter today (and will be more so in the future) compared to the 1975-vehicles analyzed in the Reactor Safety Study. Assuming that vehicles involved in an evacuation will be 30% lighter than 1975 vehicles,[45] the appropriate shielding factor range turns out to be 0.53-0.78[46]

The relative contribution of various doses, including car and skin deposition doses, can be obtained as follows.

Dose per unit time (Relative to dose from a flat, contaminated plane):[47]

A) to person standing on contaminated beach, parking lot, road, etc.	1.0 X Sg[48]
B) Dose inside car from contaminated ground	1.0 X Sc[49]

45/ Due especially to the decrease in the amount of steel used in U.S.-built cars, the material weight of U.S. cars dropped 15% between 1975 and 1981 and is projected to drop another 15% by 1985. (Table 4.3, p. 122, Transportation Energy Data Book, edition 6, G. Kulp, M.C. Holcomb, ORNL-5883 (special), Noyes Data Corporation.)

46/ Shielding varies exponentially with mass per unit area. Thus $(.4)^{.7} = 0.53$; $(.7)^{.7} = 0.78$.

47/ In the absence of detailed calculations, we assume that absorption effects in air can be handled by neglecting all absorption at distances less than 100 meters and by treating absorption beyond 100 meters as total. Thus, we replace the exact problem of a contaminated plane of infinite extent by a finite circular surface of radius 100 meters. Since the integral over the disk turns out to be logarithmic with radial distance, the total dose is insensitive to the cutoff distance chosen. These calculations are conservative since they ignore ground scattering effects which increase relative doses from deposition close to the receptor.

Deposition is assumed to proceed uniformly on any external surface regardless of the surface's orientation. Thus, a square centimeter of ground is assumed to receive the same contamination as a square centimeter of skin.

48/ Shielding factor, Sg = 0.47-0.85. See footnotes 26 and 60.

49/ Shielding factor, Sc = 0.53-0.78. See footnotes 26 and 60.

C) Dose inside car from radioactivity deposited on outside of vehicle — .22 X Sc 50/

D) Dose inside car from radioactivity deposited on inside of vehicle with open windows — .04 -.2 51/

E) Dose from skin contaminated while outside vehicle — .35 52/

F) Dose from skin contaminated while inside vehicles with open windows — .17 53/

50/ Based on numerical integration over an idealized automobile, deposition is assumed to take place on the underside of the vehicle as well as on the top surface.

51/ This case would occur 1) if windows had been left open, or 2) if evacuees reached their vehicles and opened windows before plume passage were complete.

The low number corresponds to low wind speeds; the high number corresponds to high wind speeds.

52/ An estimate of the relative contribution of skin contamination to the total dose can be obtained by replacing the complex shape of the human body with a set of bounding geometric surfaces:

1) sphere: the dose rate at the center of a sphere contaminated with N curies of radioactivity per square centimeter is 43% of the dose rate 1 meter above a circle of 100 meter radius that has also been contaminated with N curies per unit area.

   Although a cylindrical model would be more accurate, the results will not differ by a large amount, as shown below.

2) right circular cylinder: numerical integration in the case of a cylinder with radius 1/10th of the length indicates that the average centerline dose is approximately 17% greater than the sphere center dose discussed previously. For a cylinder with radius 1/5th of the length, the average centerline dose is slightly less than the sphere case.

The results of these rough calculations suggest that direct contamination of people must make a significant contribution to the total dose. We take the numerical relationship to be 35%, that is the skin contribution is assumed to be 35% of the dose from contaminated ground.

53/ We take this dose to be half of the value for a person standing in the open, assuming that half of a person's surface area is pressed against a seat and, therefore, not subject to deposition.

The total dose can be obtained by multiplying each of the above dose components by the amount of time spent under each set of conditions. Unfortunately, there are a number of time parameters that must, in principle, be specified to calculate a dose precisely. Rather than make a complex model, we have chosen to simplify the calculations by ignoring a number of effects that should tend to cancel:

1) We ignore the finite duration of the plume, that is, we assume radioactivity is deposited instantaneously. This is equivalent to adding 30 minutes to the evacuation clear time for S6V releases, 15 minutes for the S1 release.
2) We ignore doses from skin and car received after evacuees reach reception centers. This neglected dose should compensate for the above simplification.
3) In cases when skin contamination is assumed to take place, we assume that at least some evacuees remain outside vehicles during the entire time that the plume passes. This appears to be a reasonable assumption, given the fact that traffic will be stalled and it will be uncomfortable inside vehicles that do not have air conditioning.
4) In cases when car deposition is included, we assume that a significant number of evacuees who leave their vehicles to cool off (while waiting for traffic to move) will stand next to, or lean on, a contaminated vehicle.

The net result is that we numerically calculate doses to beachgoers in one of two ways:

> When skin deposition is neglected, we assume that the last group of evacuees remains inside or close to cars, stalled in traffic, while exposed to contaminated ground. Doses do not begin to accumulate until the wind carries the plume to the vehicle. Doses continue to accumulate until the clear time is reached, at which point evacuees are assumed to leave contaminated ground instantaneously and exit their vehicles.
>
> When skin deposition is not neglected, evacuees are assumed to receive the above dose plus the dose from skin contamination that is accumulated up until the clear time.

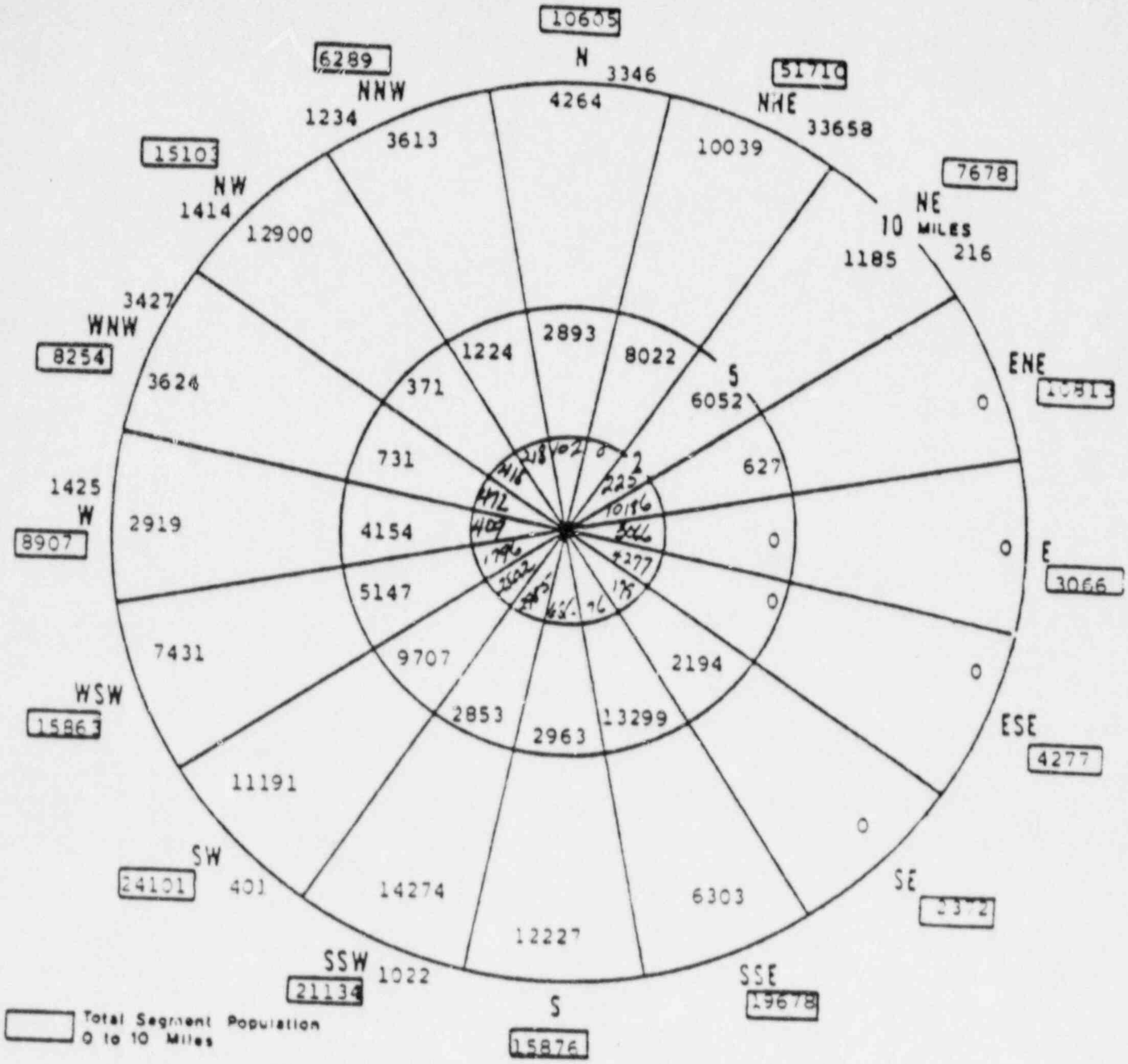
These assumptions lead to an effective dose shielding factor range of 1.0-1.3, when skin contamination is included, and a range of 0.65-0.95 when it is not.

In our judgment, the net effect of these simplifications is to underestimate the high end of the dose spectrum.

Tables 10, 17, and 18 (to be presented later) were calculated for winter populations, which are initially indoors. In these cases we have assumed cloud and inhalation sheltering factors of around 0.75. We have also assumed, for simplicity, a building shielding factor range that is identical to the automobile case (0.53-0.78).

Q. How many people are located near the plant?

A. (Beyea) The size of the beach area population around Seabrook is uncertain. One estimate of this population has been made by Public Service of New Hampshire and is found in Figure 6. Although its accuracy is uncertain, this estimate



POPULATION TOTALS			
RING, MILES	RING POPULATION	TOTAL MILES	CUMULATIVE POPULATION
0-2	27896	0-2	27896
2-5	60237	0-5	88133
5-10	89961	0-10	176094
10-B	47632	0-B	225726

Figure 6 Scenarios 3 and 4: Summer Weekday Population

does indicate that a substantial number of people are located within two miles of the plant. Estimates by other witnesses in this proceeding are much higher.

The number of persons who would be located within a plume obviously varies not only with wind direction but also with stability class and distance from the plant. At two miles the plume could be viewed as being between a 29-wedge (A stability class) and a 13-wedge (D stability class)[54/] compared to the 22.5 population wedges in the table.

Q. How large are doses likely to be and how do they compare with doses that would be received at other sites?

A. (Beyea) In order to gain a better appreciation of the higher risk faced by the beach population (higher than that faced by residents at comparable distances at other sites for comparable releases), we present a series of Tables that show radiation doses likely to be received under various scenarios. Table 8 shows the highest-risk case, which applies to the Seabrook beach population that is separated from the reactor by a lagoon. (Because plumes disperse less over water, the plume is more concentrated by the time it reaches the population than had it traveled over land.)

The doses shown apply to a person assumed to leave the contaminated area after 5 hours. The doses are truly enormous for the S6V-Total release. (Note that a 500-rem dose has a

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54/ Wedges are assumed to have plume widths of 3 times the horizontal dispersion coefficient.

TAB

DOSES RECEIVED ON A SUMMER DAY BY HIGHEST-RISK POPULATION ON SEABROOK BEACH[a]
(SKIN & CAR DEPOSITION DOSE INCLUDED)

Stability[c)] Class	Wind Speed (m/sec)	Dose 5 Hrs After Evacuation starts[b)] (In Rem) PWR1 S1[e)]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d)] S1[e)]	S6V-tot.	S6V-1
A	2	63-74	230-270	<50	N	Y	N
A	4	160-190	120-150	<50	N?	N?	N
A	8	120-140	65-76	<50	N?	N	N
B	2	<50	580-6[illegible]	85-98	N	Y	N
B	4	<50	320-380	48-55	N	Y	N
B	8	180-220	170-2[illegible]	<50	Y	Y	N
C	2	<50	1600-1900	230-270	N	Y	Y
C	4	"	900-1100	130-150	N	Y	N
C	8	"	490-590	70-83	N	Y	N
D	2	"	2700-3200	379-448	N	Y	Y
D	4	"	1600-1900	222-264	N	Y	Y
D	8	"	840-1000	120-143	N	Y	N?

a) The population at 2 mi. with bay water between reactor and beach.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car and directly on the individual. The effective ground shielding factors range from 1.0 to 1.3, depending on the type of automobile. See Question 13 for further details.
c) Pasquill stability class. Dispersion parameters were shifted by one stability class to account for reduced dispersion over water. (See W.A. Lyons, "Turbulent Diffusion and Pollutant Transport in Shoreline Environments", in Lectures on Air Pollution and Environmental Impact Analyses. American Meteorological Society, 45 Beacon Street, Boston, MA 02108, (1985). Pages 141, 142, and especially Figure 25 on Page 149.)
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) Assuming mid-range plume rise.

mortality rate greater than 70%.) As discussed below, doses exceed the threshold for meteorological conditions that hold 93% of the time.

The doses for an S6V-1 release are smaller than for S6V-Total, but still exceed threshold for meteorological conditions that hold about 33% of the time. Doses shown for the high-rising S1 release have been calculated using a standard plume rise formula, so they almost always remain below threshold. (However, as mentioned earlier, the occurrence of a low-rising plume is expected frequently. For this reason, we continue to list probability values under the yes/no columns in Table 8 that indicate whether or not there is a risk of early death.)

Not all of the 2-mile beach population is separated from the reactor by water. Table 9 shows the results for populations separated by land. The doses are still extraordinarily high for the S6V-Total release, but are significantly less serious for an S6V-1 release. It is of interest to compare these results with doses that would be accumulated at the median reactor site around the United States. The results are shown in Table 10. We have taken 1.5 hours for the evacuation clear time within 2 miles, based on an NRC estimate of the median time.[55/]

55/ T. Urbanik II, "An Analysis of Evacuation Time Estimates Around 52 Nuclear Power Plants," Nuclear Regulatory Commission, Washington, NUREG/CR-1856 (1981), Vol. I, Table 10, p. 21.

TABLE 9

DOSES RECEIVED ON A SUMMER DAY BY 2-MILE BEACH POPULATION[a)]
(SKIN & CAR DEPOSITION DOSE INCLUDED)

Stab-[c)] ility Class	Wind Speed (m/sec)	Dose 5 Hrs After Evacuation starts[b)] (In Rem) PWR1 $\overline{S1}$[e)]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d)] $\overline{S1}$[e)]	S6V-tot.	S6V-1
A	2	122-143	95-110	<50	N	N	N
A	4	92-109	50-59	<50	N	N	N
A	8	53-62	<50	<50	N	N	N
B	2	63-74	230-270	<50	N	Y	N
B	4	160-190	120-150	<50	N?	N?	N
B	8	120-140	65-76	<50	N	N	N
C	2	<50	580-680	85-98	N	Y	N
C	4	<50	320-380	48-55	N	Y	N
C	8	180-220	170-200	<50	Y	Y	N
D	2	<50	1600-1900	230-270	N	Y	Y
D	4	<50	900-1100	130-150	N	Y	N
D	8	<50	490-590	70-83	N	Y	N

a) The population two miles from the plant, but not directly across the lagoon.

b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car and directly on the individual. The effective ground shielding factors range from 1.0 to 1.3, depending on the type of automobile. See Question 13 for further details.

c) Pasquill stability class.

d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.

e) Assuming mid-range plume rise.

TABLE 10

DOSES RECEIVED BY 2-MILE POPULATION[a)]
AT A MEDIAN REACTOR SITE IN THE UNITED STATES
(CAR DEPOSITION DOSE INCLUDED)

Stab-[c)] ility Class	Wind Speed (m/sec)	Dose 1.5 Hrs After Evacuation Starts[b)] (In Rem) PWR1 $\overline{S1}$[e)]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d)] $\overline{S1}$[e)]	S6V-tot.	S6V-1
A	2	53-60	<50	<50	N	N	N
A	4	<50	<50	<50	N	N	N
A	8	<50	<50	<	N	N	N
B	2	<50	95-110	<	N	N	N
B	4	71-82	52-58	<50	N	N	N
B	8	52-61	<50	<50	N	N	N
C	2	<50	220-250	<50	N	Y	N
C	4	<50	130-140	<50	N	N?	N
C	8	78-91	67-76	<50	N	N	N
D	2	<50	540-610	77-87	N	Y	N
D	4	"	320-370	<50	N	Y	N
D	8	"	170-200	<50	N	Y	N

a) The population two miles from the plant.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by buildings and their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car, but they are not assumed to have had their skin contaminated. The effective ground shielding factors range from 0.65 to 0.95, depending on the type of automobile. Cloud and inhalation shielding factors are taken to be 0.75. See Question 13 for further details.
c) Pasquill stability class.
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) Assuming a mid-range plume rise.

Table 10 shows that doses, even for S6V-Total, get very high only for two meteorological conditions (D-stability, wind speeds 2 and 4 meters/second). Doses for the other releases never rise above early-death threshold. In general, doses at these other sites are less than one-fifth the doses for the highest-risk Seabrook beach case.

Q. Are the beach populations beyond two miles exposed to risk of early death during a summer day?

A. (Beyea) Yes, certainly for an S6V-Total release. Tables 11 and 12 show the calculated results for beach populations at 4 miles and an evacuation time of 5 hours. Note that the beach population is not protected for a low-rising S1 release either.

Additional insight into how far from the reactor threshold doses are likely to occur for an S6V-Total release can be gained from examining Table 13. It shows early death radii for D-stability class and a five-hour evacuation time. This means that an individual remaining in the plume at a radius given in the last column of the table for five hours under the given weather conditions will receive at least a 200-rem dose. These are the individuals who have not been able to evacuate earlier due to traffic congestion, etc. It should be noted, however, that individuals at this radius who have evacuated earlier may still receive a 200-rem dose due to the continuing dose contribution from material deposited on their skin and car. Similarly, individuals beyond the early death radius for a

TABLE 11

DOSES RECEIVED ON A SUMMER DAY BY 4-MILE BEACH POPULATION[a)]
(SKIN AND CAR DEPOSITION DOSES INCLUDED)

Stab-[c)] ility Class	Wind Speed (m/sec)	Dose 5 Hrs After Evacuation Starts[b)] (In Rem) PWR1 $\overline{S1}$[e)]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d)] $\overline{S1}$[e)]	S6V-tot.	S6V-1
A	2	61-71	48-55	<50	N	N	N
A	4	<50	<50	<50	N	N	N
A	8	<50	<50	<50	N	N	N
B	2	82-96	59-69	<50	N	N	N
B	4	64-75	<50	<50	N	N	N
B	8	<50	<50	<50	N	N	N
C	2	<50	160-190	<50	N	N?	N
C	4	98-120	97-110	<50	N	N	N
C	8	93-110	52-61	<50	N	N	N
D	2	<50	540-640	77-89	N	Y	N
D	4	<50	340-410	50-58	N	Y	N
D	8	<50	190-230	<50	N	Y	N

a) The population 4 miles from the plant.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car and directly on the individual. The effective ground shielding factors range from 1.0 to 1.3, depending on the type of automobile. See Question 13 for further details.
c) Pasquill stability class.
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) Assuming a mid-range plume rise.

TABLE 12

EXPOSURE OF 4-MILE BEACH POPULATION[a] TO RISK OF EARLY DEATH ON A SUMMER DAY (SKIN & CAR DEPOSITION DOSES INCLUDED)

Stab-[c] ility Class	Wind Speed (m/sec)	Time in hours to Reach[b] 200 Rem: PWR1 $\overline{S1}$[e]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d] $\overline{S1}$[e]	S6V-tot.	S6V-1
A	2	19-24	23. ->24	>24	N	N	N
A	4	>24	>24	>24	N	N	N
A	8	>24	>24	>24	N	N	N
B	2	13-17	18. - 23	>24	N	N	N
B	4	18-24	>24	>24	N	N	N
B	8	>24	>24	>24	N	N	N
C	2	>24	5.4- 6.7	12-15	N	Y	N
C	4	11-14	10.5-13.5	23->24	N	N	N
C	8	12-15	21.6->24	>24	N	N	N
D	2	>24	<1	3.5-4.2	N	Y	Y
D	4	>24	1.7- 2	6.8-8.6	N	Y	N?
D	8	>24	4- 5.2	14-18	N	Y	N

a) The population 4 miles from the plant.

b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car and directly on the individual. The effective ground shielding factors range from 1.0 to 1.3, depending on the type of automobile. See Question 13 for further details.

c) Pasquill stability class.

d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.

e) Assuming a mid-range plume rise.

given set of conditions are not necessarily protected from a 200-rem dose, because we have not accounted for the doses they might receive outside the plume from skin and car deposition material.

As noted previously, if evacuation times for the beaches beyond 2 miles are longer than 5 hours, as is documented by Adler, the consequences of these releases for a given set of conditions will be more serious. The early death radii will be larger and many more people will be exposed.

Q. How would a summer evening scenario affect your results?

A. (Beyea) There is evidence that there would still be a substantial population on or near the beaches on summer evenings. Although evacuation times might be reduced due to a smaller evacuating population, it is not clear that this reduction would be enough to ensure that no early deaths occurred in the population--especially since night-time plumes are more concentrated and therefore are more dangerous. In order to investigate the consequences of a summer evening scenario, we have obtained an estimate from our model of the doses at 2 miles which would be received for typical evening weather scenarios assuming a clear time of 1.5 hours. We have assumed, in contrast to the summer scenario, that the population is wearing more clothes and could remove them after exposure to reduce the skin deposition dose. While it is very uncertain how much this would reduce the skin deposition dose, we have also assumed for simplicity that removing clothes would eliminate it, including the contribution from contaminated hair. We have still assumed a dose component from material deposited on cars. (The dose scaling factor range for this scenario becomes .65-.95)

The results of our model are shown in Table 13a. The time to reach 200 rem is usually one hour or less for the S6V-total release, which means that any reduction of evacuation times during the evening is not going to protect the population for this release category.

Q. How frequently do the various weather conditions occur?

A. (Beyea) The frequencies of the Pasquill stability classes, as reported in the SB 1&2, ER-OLS,[56] are given in Table 14. The frequencies of the A,B, and C stability classes increase during the summer months, with C the most frequent of the three. D and E are the dominant stability classes. Although not indicated in the Table (which is based on 24 hour data), C and D stability classes would probably dominate during daytime hours because the E, F, and G stability classes tend to occur primarily in the evening or early morning hours.

The consequences during C, D, and E classes are all serious in terms of early death. Consequences would also be serious

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56/ Public Service of New Hampshire, "Seabrook Station - Units 1 & 2, Environmental Report, Operating License Stage," Figure 2.1-19.

TABLE 13

EARLY DEATH RADII FOR A 5-HOUR EVACUATION TIME

ON A SUMMER DAY

S6V-TOTAL RELEASE

STABILITY CLASS	WIND SPEED (m/sec)	EARLY DEATH RADIUS (miles)[a)]
B	2	2-3
B	4	1-2
B	8	1-2
C	2	3-4
C	4	2-3
C	8	1-2
D	2	7-8
D	4	6-7
D	8	4-5

a) An individual in the plume at this radius under the given conditions will receive, assuming a five-hour clear time, at least a 200 rem dose. Individuals at this radius who have evacuated earlier may still receive at least a 200 rem dose due to the continuing dose contribution from material deposited on their skin and car. Individuals at farther distances may still receive 200 rem doses due to skin and car deposition doses after leaving the plume.

A dose scaling factor range of 1.0-1.3 is assumed. This is equivalent to assuming 1) that some individuals are caught in the open during plume passage, 2) that the last to evacuate are stuck in traffic and spend the full five hours in contaminated ground, and 3) that all doses cease after five hours. See Question 13 for further details.

TABLE 13a

DOSES RECEIVED ON A SUMMER EVENING BY TWO-MILE BEACH POPULATION[a]
(CAR DEPOSITION DOSE INCLUDED, NOT SKIN DOSE)

		Dose 3 Hrs After Evacuation starts[b] (In Rem)			Risk of Early Death?[d]		
Stab-[c] ility Class	Wind Speed (m/sec)	PWR1	PWR2	PWR3			
		$\overline{S1}$[e]	S6V-total	S6V-1	$\overline{S1}$[e]	S6V-tot.	S6V-1
D	2	<50	820-970	120-140	N	Y	N
D	4	"	480-560	72-81	N	Y	N
D	8	"	260-310	<50	N	Y	N
E	2	"	1300-1600	200-220	N	Y	Y
E	4	"	790-950	120-130	N	Y	N
E	8	"	430-520	64-73	N	Y	N

a) The population 2 miles from the plant, not directly across the lagoon. Doses would be higher should the plume be blowing over the lagoon.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car. No skin dose is included on the assumption that a) clothes keep radioactivity from reaching skin; and b) that clothes are discarded once evacuees enter their cars. The effective ground shielding factors range from 0.65 to 0.95, depending on the type of automobile. See Question 13 for further details.
c) Pasquill stability class.
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) Assuming a mid-range plume rise.

TABLE 14

FREQUENCY OF PASQUILL STABILITY CLASSES AT SEABROOK(a)
(Values in % of Time)

Month	A	B	C	D	E	F	G
Apr 1979	1.27	2.11	3.80	49.65	29.40	7.88	5.91
May	1.20	2.86	4.82	52.86	26.51	5.27	6.48
Jun	2.92	6.69	12.26	39.83	25.49	6.13	6.69
Jul	4.90	6.94	11.56	29.12	28.84	12.65	5.99
Aug	2.91	4.71	9.97	43.07	26.59	7.34	5.40
Sep	1.25	7.64	11.81	30.69	27.36	10.83	10.42
Oct	0.81	2.96	5.79	39.30	34.05	10.09	7.00
Nov	0.00	0.56	4.76	43.92	34.83	9.37	6.57
Dec	0.00	0.41	2.70	47.03	41.35	5.81	2.70
Jan 1980	0.13	1.88	6.59	51.88	30.38	5.78	3.36
Feb	0.44	2.03	5.37	50.36	34.69	5.66	1.45
Mar	10.68	1.64	5.34	43.15	24.66	6.03	8.49
Yearly	2.22	3.37	7.08	43.31	30.38	7.76	5.87

a) Period of Record: April 1979 - March 1980. Stability class calculated using 43'-209' delta temperature. Source: SB 1&2, ER-OLS, Table 2.3-24.

TABLE 15

JOINT FREQUENCY DISTRIBUTION OF WIND SPEED, AND STABILITY CLASS FOR SEABROOK[a] (209-FOOT LEVEL)[b]

APRIL '79 - MARCH '80

Stability Class	Wind Speed (mph)	Wind Speed (m/sec)	% Within Class
A	<4	<1.8	1.04
	4-7	1.8-3.1	8.85
	8-12	3.6-5.3	31.77
	>12	>5.3	58.33
B	<4	<1.8	1.03
	4-8	1.8-3.1	10.65
	8-12	3.6-5.3	42.[illegible]7
	>12	>5.3	46.[illegible]5
C	<4	<1.8	2.29
	4-7	1.8-3.1	17.51
	8-12	3.6-5.3	36.50
	>12	>5.3	43.6[illegible]
D	<4	<1.8	3.34
	4-7	1.8-3.1	17.92
	8-12	3.6-5.3	36.70
	<12	>5.3	42.03
E	<4	<1.8	4.57
	4-7	1.8-3.1	16.78
	8-12	3.6-5.3	44.32
	>12	>5.3	34.33

a) Source: SB 1&2, ER-OLS, Table 2.3-27.

b) Frequency distribution would vary with measurement level and season.

for F and G conditions though we have not considered them. Our results are not based on an infrequently occurring weather scenario.

The distribution of wind speeds within the stability classes is given in Table 15.[57/] Note that these distributions are not disaggregated by season, and the summer distribution might be different.

Although the frequency data given in Tables 14 and 15 are not precisely applicable to earlier tables, it is possible to use the information to make a rough assessment of the probability that the population would not be protected from early death should a severe release occur with the wind blowing toward a beach. For instance, it was indicated in Table 9 that for an S6V-total release, the 2-mile beach population on a summer day was not protected from early death under C and D conditions. These meteorological conditions are likely to occur 75% of the time during summer days.[58/] The probability is even higher for the highest-risk Seabrook beach population -- around 93%.

Q. What about the S6V-1 release?

57/ New Hampshire Emergency Response Plan, Rev. 2., Vol. 6, p. 10-52.

58/ This assumes that C and D stability classes occur with a 75% probability on a summer day (E, F, and G do not occur during the day and about one half of the D percentages in Table 14 occur at night.)

A. In this case, a similar analysis suggests that doses exceeding threshold would occur about one-third of the time for the highest-risk population at Seabrook beach, if it were downwind.59/

Q. How many people would be contaminated during a summer release?

A. (Beyea) It must be recognized that, based on Tables 6, 9, and 11, thousands of people might be exposed to life-threatening doses should a release occur on a summer day.

In order to put some bounds on the health consequences to a beach area population, we have done a simple calculation of the number of people who might be contaminated due to a release at Seabrook. An unknown fraction of this number would receive doses at or above 200 rem. The others might suffer a range of consequences, from nausea within a few hours to cancer many years in the future.

The lower bound to this limit is zero; that is, with enough warning time, it is possible that no one will be contaminated. The maximum number of persons contaminated within ten miles

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59/ The S6V-1 column in Table 8 indicates that the early death threshold would occur for 1) D stability class and wind speeds of 2 and 4 m/sec, and 2) C stability class and wind speeds around 2 m/sec.

According to Table 15, the D wind speeds would occur 60% of the time, while the C wind speeds would occur 18% of the time. The net result, based on the data for summer months in Table 14, is a 28% chance of early death threshold under D conditions and a 5% chance under C conditions.

during an accident on a summer weekday is listed in Table 16, for a low estimate of weekday population taken from New Hampshire Seabrook Plan. (See testimony of other experts in this proceeding for an explanation of why the actual population may be considerably higher.) The table shows a range of between 10,000 and 23,000 people who may be exposed.

The table assumes no one within ten miles will have had sufficient time to evacuate before passage of the plume. The purpose of the table is basically to show the size of the population that may be of immediate concern--those persons within ten miles who will know they may have been exposed, later will presumably learn that they have been exposed, and who will wonder what the potential consequences will be.

The maximum number is so large that it is questionable whether medical facilities will be adequate to treat those seeking treatment.

Q. Is the population exposed to "early death" during other times of the year?

A. (Beyea) Yes. We prepared Tables 17 and 18 in a manner similar to those for a summer day beach scenario and found that the population is not always protected from "early death" (200 rem) at two and four miles for the rapid bypass sequence, S6-V total, although the population is protected for other sequences considered.

For those tables we examined evacuees who would take about three hours to evacuate as shown in Table 19. During plume

TABLE 16

VARIATION IN POPULATION EXPOSED IN SSE SECTOR WITHIN 10 MILES ON A SUMMER WEEKDAY

STABILITY CLASS	PLUME ANGLE[a] AT 5 MILES (degrees)	MAXIMUM EXPOSED POPULATION[b]
A	26	23,000
B	20	18,000
C	15	13,000
D	11	10,000

a) Assumes a plume angle of three times the horizontal dispersion coefficient.

b) Calculated as the population in the SSE sector (20,000) according to figure 6 multiplied by the ratio of plume angle to 22.5 degrees. Minimum population could be zero if the wind were blowing towards the ocean and there were sufficient warning time of a release.

TABLE 17

DOSES RECEIVED AT 2 MILES ON AN OFF-SEASON WEEKDAY[a]
(CAR DEPOSITION DOSE INCLUDED)

Stab-[c)] ility Class	Wind Speed (m/sec)	Dose 3 Hrs After Evacuation starts[b)] (In Rem)			Risk of Early Death?[d)]		
		PWR1	PWR2	PWR3			
		$\overline{S1}$[e)]	S6V-total	S6V-1	$\overline{S1}$[e)]	S6V-tot.	S6V-1
A	2	62-73	48-55	<50	N	N	N
A	4	47-56	<50	"	N	N	N
A	8	<50	[illegible]	"	N	N	N
B	2	"	110-140	"	N	N	N
B	4	83-94	62-72	"	N	N	N
B	8	60-73	<50	"	N	N	N
C	2	<50	270-320	"	N	Y	N
C	4	<50	150-180	"	N	N?	N
C	8	93-110	81-94	"	N	N	N
D	2	<50	690-940	97-120	N	Y	N
D	4	<50	410-490	59-68	N	Y	N
D	8	<50	220-270	<50	N	Y	N

a) The resident population two miles from the plant.

b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by buildings and their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car. The effective ground shielding factors range from 0.65 to 0.95, depending on the type of automobile. Cloud and inhalation shielding factors are taken to be 0.75. See Question 13 for further details.

c) Pasquill stability class.

d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.

e) Assumes mid-range plume rise.

passage, residents were assumed to be inside buildings with cloud and inhalation shielding factors of 0.75. We assumed a ground-dose scaling factor of 0.65-0.95, implying that the evacuees were in cars within the plume, and that the cars had radioactive material deposited on them. No skin deposition dose was assumed.

Although Table 17 shows several "unprotected" cases for the rapid bypass sequences at two miles, it should be noted that the actual doses above threshold would be considerably higher in the summer time. Doses to the highest-risk beach population would be about four times as high as those projected for an off-season accident. (At four miles the corresponding ratio would be two to one.) As a result of these higher doses, the total number of injuries would be greater in the summer even if the exposed populations were the same.

Furthermore, because the population during the off-season scenarios is smaller than for summer scenarios, fewer people would receive radiation doses during off-season scenarios. Therefore, there would be less of a chance that medical facilities would be overwhelmed, and more of a chance that most of those exposed to doses about 200 rem would receive the "supportive" medical treatment that would be needed to raise the early death threshold above 200 rem. This would be particularly important for the 4-mile case shown in Table 18.

Q. What difficulties are associated with reducing the health consequences of a large release at Seabrook?

TABLE 18

DOSES RECEIVED AT 4 MILES ON AN OFF-SEASON WEEKDAY[a)]
(CAR DEPOSITION DOSE INCLUDED)

Stability Class[c)]	Wind Speed (m/sec)	Dose 3 Hrs After Evacuation Starts[b)] (In Rem) PWR1 $\overline{S1}$[e)]	PWR2 S6V-total	PWR3 S6V-1	Risk of Early Death?[d)] $\overline{S1}$[e)]	S6V-tot.	S6V-1
A	2	<50	<50	<50	N	N	N
A	4	"	"	"	N	N	N
A	8	"	"	"	N	N	N
B	2	"	"	"	N	N	N
B	4	"	"	"	N	N	N
B	8	"	"	"	N	N	N
C	2	"	78-92	"	N	N	N
C	4	50-58	47-55	"	N	N	N
C	8	47-56	<50	"	N	N	N
D	2	<50	240-280	"	N	Y	N
D	4	"	160-190	"	N	N?	N
D	8	"	93-100	"	N	N	N

a) The resident population four miles from the plant.
b) Persons caught in the plume are assumed to be partially shielded from contaminated ground by buildings and their vehicles. They are assumed to receive a dose component from radioactive material deposited on the car. The effective ground shielding factors range from 0.65 to 0.95, depending on the type of automobile. Cloud and inhalation shielding factors are taken to be 0.75. See Question 13 for further details.
c) Pasquill stability class.
d) "Y" indicates exposure to a 200-rem dose or higher. An evacuation time of 5 hours is assumed. A question mark by an entry indicates that even though doses do not reach the 200-rem early death threshold, the 100-rem threshold for nausea has been reached. In such cases, the assumed 5-hour evacuation time may be suspect.
e) Assumes mid-range plume rise.

TABLE 19

SEABROOK EVACUATION CLEAR TIME ESTIMATES[a)]

OFF-SEASON WEEKDAY SCENARIO

RADIUS	DEGREES	HMM[b)]	Vorhees[c)]	Maguire[d)]	NRC[e)]
0-2	360	3:10	-	-	-
0-5	360	3:10	-	-	-
0-10	360	4:30	3:40	3:00	6:45

a) Time (Hours:minutes) for the population to clear the indicated area afte notification.

b) "Preliminary Evacuation Clear Time Estimates for Areas Near Seabrook Station," HMM Document No. C-80-024A, HMM Associates, Inc., May 20, 1980.

c) "Final Report, Estimate of Evacuation Times," Alan M. Vorhees & Associates, July 1980.

d) "Emergency Planning Zone Evacuation Clear Time Estimates," C.E. Maquire, Inc., February 1983.

e) Letter to Mitzie Solberg, Emergency Preparedness Development Branch, U.S. N.R.C. from A.E. Desrosiers, Health Physics Technology Section, Battelle, Pacific Northwest Laboratories, August 20, 1982.

A. (Beyea) Limited options exist for reducing the severity of accidents at Seabrook.

None of the extraordinary emergency measures that we, or other nuclear analysts have been able to devise are likely to eliminate or effectively reduce the serious radiation doses that would result from a range of releases at Seabrook.

(A) Possibility of reducing skin and car deposition dose.

Our work here has shown that skin and car deposition doses could make important contributions to the total dose to an individual, but no consideration has been given to reducing these doses in emergency planning. We have considered whether or not extraordinary emergency measures could be taken to protect against them. For instance, evacuees could be instructed to leave the evacuation vehicle as soon as possible, to shower (skin and hair) as soon as possible, and perhaps to remove hair with scissors. Automated car spraying devices could be installed near important beach exit points in an attempt to remove some of the material from cars as soon as possible, thus reducing doses to the occupants. The effectiveness of various methods for removing radioactive aerosols from skin, hair, and cars must be investigated, however, before credit can be taken for them. The logistics of washing every car in the beach area would be formidable and would likely add to evacuation times. (Removal of aerosols is complicated by the fact that radioactive aerosols attach themselves too strongly to clean surfaces to be removed easily. On the other hand, the fraction depositing on dirty or oily surfaces could be removed at the same time as dirt and oil were removed.)

All these measures, if they worked, could be helpful in reducing the number of delayed cancers that would show up in later years. However, their implementation would not change the significance of our tables with respect to early health effects. This is because post-evacuation doses are not even considered in our calculations and because not all cars could be decontaminated. Also, populations are not protected, even when car deposition doses are excluded.

B) Possibility of relying on shelters.

In principle, one way to reduce the chances of early death occurring in the beach population would be to provide shielding by means of sheltering, especially from ground dose, while people wait for roads to clear. However, shelters would only be useful if they are suitably massive, which seems doubtful in this case.[60/] Serious questions exist as to whether they

60/ Z.G. Burson and A.E. Profio, "Structure Shielding from Cloud and Fallout Gamma Ray Sources for Assessing the Consequences of Reactor Accidents," EG & G, Inc., Los Vegas, Nev., EGG-1183-1670.

would actually be used by a majority of the population. As is indicated by the testimony of other experts in this proceeding, sheltering is not a realistic option for the beach populations.

The possibility of having beach occupants shield themselves by immersing themselves in ocean water has been rejected by us because of the low temperature of the water. On the other hand, it would be physically possible for exposed persons to partially shield themselves from ground dose by covering themselves with sand prior to evacuation. However, the notion that people will wait away from their cars buried in the sand or immersed in the water while traffic congestion clears seems grotesquely unrealistic.

C) <u>Possibility of evacuating on foot or by bike.</u>

The beach population might be instructed to walk out of the area. If the release has occurred, has blown towards the beaches, and has been confined to a relatively narrow area, this might be the best strategy to reduce doses from a theoretical nuclear physics perspective. In this way, no one would wait within the plume area accumulating doses from the radioactive material on the ground or on cars. Our calculations show that a person walking out in certain circumstances would have received, about five hours after the release, between a 30 to 40% lower dose than a person who has remained in a car within the plume while trying to evacuate.[61] However, this type of forced march strategy flounders when faced with normal human behavior.

Providing bicycles for beachgoers might be a strategy since it would offer the hope of relatively rapid escape. Nevertheless, it is not clear what percentage of beachgoers would utilize the bikes and what the traffic impact would be. In fact, access to bikes might increase the disorderliness of the evacuation. For example, consider those beachgoers who opted for driving (with or without official permission), only to return for bicycles after being stuck in traffic for an hour or so. Their abandoned automobiles could well block traffic for those remaining. Certainly no credit could be given in emergency planning for reliance on bicycles without a full-scale test of the process. Yet, a convincing test would be impossible. How could a test reliably simulate the stress and fear that would be generated in a real accident?

61/ We calculated the dose to an individual on the beach who waits for about one and a half hours after the release (dose scaling factor of 1.35), who then leaves the plume, but accumulates doses from skin deposition (dose scaling factor .35). We also calculated the dose to an individual in a car within the plume, accumulating doses from the plume on skin and car deposition material (dose scaling factor of 1.0-1.3). By comparing the doses for about five hours after the release, we found a 30-40 percent lower dose for those individuals walking out.

D) Possibility of pre-distributing potassium iodide.

The value of pre-distributing potassium iodide near nuclear power plants has been discussed by us previously. However, pre-distribution will not work for a transient beach population, unless the authorities are willing to hand out tablets every day to everyone who visits the beaches. Also, potassium iodide would be of limited usefulness for the high-dose scenarios that would develop at Seabrook beaches.

Q. What about the probability of the releases discussed in your testimony?

A. (Beyea) PWR1-PWR9 releases are established by NUREG-0396 as the spectrum of releases that must be considered in emergency planning for nuclear power plants. The NRC took the probability and credibility of these accidents classes into account in developing NUREG-0396. Every emergency plan, therefore, must address the entire range of these releases, and should also examine the site-specific equivalent of these generic releases.

Q. What is your overall assessment of the doses that might be delivered at Seabrook?

A. (Beyea) The summer Seabrook situation is the worst case I have ever examined in connection with emergency planning or hypothetical reactor accidents. The doses that would be received following a range of releases at the Seabrook site, even with the proposed emergency plans in effect, are higher than doses that would be received at most other sites in the complete absence of emergency planning.

Q. Dr. Beyea, does that complete your testimony?

A. (Beyea) Yes, it does.

X. PWR-1 RELEASES AT SEABROOK

Q. Dr. Thompson, what is the basis for your statements in your testimony?

A. (Thompson) As mentioned earlier, I have co-authored a review (Sholly and Thompson, 1986) of various "source term" issues. This review was current through mid-1985. I used that review and the documents cited within it as a basis for my statements. In addition, I have studied a variety of more recent documents, which collectively form the remaining basis for my statements. These more recent documents include the draft NRC report NUREG-1150 (NRC, 1987a) and the documents generated as a result of a January 1987 technical meeting sponsored by the NRC (Kouts, 1987; NRC 1987b). (See attached references.)

Q. Please describe the potential for a "PWR1-type" release.

A. (Thompson) The Reactor Safety Study (NRC, 1975) described the PWR1 release category as being "characterized by a core meltdown followed by a steam explosion on contact of molten fuel with the residual water in the reactor vessel." More recent work has identified the potential for a similar release through a different mechanism--high-pressure melt ejection. In this case, molten core material is expelled from the reactor vessel under pressure of steam and gases within the vessel.

Q. Where might the containment breach occur during an accident sequence leading to a "PWR 1-type" release?

A. (Thompson) For either steam explosion or high-pressure melt ejection sequences, the location of the breach cannot be predicted. The breach might occur anywhere from the base of the containment wall to the containment dome. In addition, a co-existing bypass pathway could lead to some release through buildings adjacent to the main containment building.

Q. Please describe the range of thermal energy release rates which could be experienced during a "PWR 1-type" release.

A. (Thompson) This range is illustrated by Figure 7, which is drawn from the Seabrook Station Probabilistic Safety Assessment (PLG, 1983). For present purposes, release category S1 is relevant. The table shows that the estimated energy release rate for this release category could vary from 21,000 million BTU per hour to 60 million BTU per hour, according to the size of the containment leak area. Present knowledge of containment failure modes is

TABLE 11.6-4. ENERGY RELEASE RATES FOR RELEASE CATEGORIES $\overline{\text{ST}}$, $\overline{\text{S3}}$, $\overline{\text{S3V}}$, AND $\overline{\text{S4V}}$

Release Category	Energy Released (10^8 Btu)	Energy Release Rate (10^9 Btu/hr)				
		Blowdown Duration				
		10 Seconds	2 Minutes	10 Minutes	30 Minutes	1 Hour
$\overline{\text{ST}}$	0.58	21	3.5	0.35	0.12	0.06
$\overline{\text{S3}}$	1.26	25	7.6	0.76	0.25	0.13
$\overline{\text{S3V}}$	2.0	70	12	1.2	0.4	0.2
$\overline{\text{S4V}}$	1.6	57	9.6	0.96	0.32	0.16
Leak Area (ft^2)		250	25	2.5	1	0.5
Equivalent Diameter (feet)		18	6	1.8	1.1	0.8

Figure 7
Source: PLG, 1983

such that the energy release rate cannot be predicted within this range, and perhaps within a wider range.

Q. Please describe the potential for "PWR 1-type" releases to be relatively enriched in certain radioactive isotopes?

A. (Thompson) In Appendix VI of the Reactor Safety Study (NRC, 1975), release category PWR1 is shown as having a relatively large release fraction for the ruthenium group of radioactive isotopes--40% for this release category as opposed to 2% for release category PWR 2. Such an enhanced release is predicted to occur because of the physical and chemical behavior of a steam explosion event. More recent studies have shown that a high-pressure melt ejection event could also lead to enchanced release of certain isotopes including those of ruthenium, molybdenium and tellurium.

Q. Mr. Thompson, does this complete your testimony?

A. (Thompson) Yes, it does.

TABLE A TO TESTIMONY OF STEVEN C. SHOLLY

SURRY DOMINANT ACCIDENT SEQUENCES, WASH-1400

The WASH-1400 analysis of Surry Unit 1 identified twelve accident sequences which dominated the estimated median core melt frequency of 5×10^{-5} per reactor-year. 1/ These twelve accident sequences, their designations, and their estimated frequencies are described below. 2/

Sequence TMLB' -- This sequence is a station blackout sequence (a loss of offsite power followed by the failure of onsite AC power and the failure to recover AC power within about three hours). WASH-1400 estimated the frequency of sequence TMLB' at 3×10^{-6} per reactor-year. 3/ 4/

1/ It will be noted that if the frequencies of those twelve sequences are summed the resultant core melt frequency is 1.24×10^{-4} per reactor-year. WASH-1400 obtained the 5×10^{-5} per reactor-year by a Monte Carlo sampling technique, the particulars of which are not especially clear. The latter value has been cited widely, and is therefore used here for reference purposes.

2/ Recently, a new risk assessment for Surry Unit 1 was performed for the draft NRC report NUREG-1150, *Reactor Risk Reference Document*. The full results of the new Surry 1 PRA are documented in Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events: Surry Unit 1*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986. This study estimated the mean frequency of core melt at 2.6×10^{-5} per reactor-year from "internal events" accidents (i.e., not including "external events" such as earthquakes, floods, fires, etc.). *Id.*, page I-4. WASH-1400 sequences TKQ, TKMQ, and S_2C were found not to lead to core melt. Other WASH-1400 sequences for Surry were identified as among the dominant core melt sequences in the new study, along with several newly-identified accident sequences. A table from NUREG/CR-4550 which summarizes the results of the newer study is provided as an addendum to Exhibit 3 for comparison purposes.

3/ N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, *"Main Report,"* page 82.

4/ The NUREG-1150 analysis of Surry identified four separate station blackout sequences. These four sequences have an aggregate core melt frequency estimated at 9.5×10^{-6} per reactor-year. See, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia

__Sequence TML__ -- This sequence is a transient either resulting from or followed by a loss of main feedwater, with a failure of auxiliary feedwater. WASH-1400 estimated the frequency of sequence TML at 6×10^{-6} per reactor-year. 5/ 6/

__Sequence V__ -- The V sequence represents an "intersystem LOCA" resulting from the failure of the low pressure injection system check valves. This results in the rupture of the low pressure injection system piping outside of the containment; the radiological release from this core melt accident also bypasses the containment. WASH-1400 estimated the frequency of sequence V at 4×10^{-6} per reactor-year. 7/ 8/

__Sequence S2C__ -- Sequence S_2C represents a small LOCA in which the containment spray injection system fails. This results in a lack of containment heat removal. The containment fails due to steam overpressure, following which the emergency core cooling systems fail due to insufficient net positive suction head (NPSH) and/or damage due to containment depressurization. This results in core melt __after__

National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 and V-6.

5/ N.C. Rasmussen, et al., __*Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*__, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 82.

6/ The NUREG-1150 analysis estimated the frequency of this type of accident sequence at 1.1×10^{-6} per reactor-year. __See__, Robert C. Bertucio, et al., __*Analysis of Core Damage Frequency From Internal Events*__, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, page V-5.

7/ N.C. Rasmussen, et al., __*Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*__, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 81.

8/ Science Applications International Corporation has re-estimated the V sequence frequency at 5×10^{-7} per reactor-year. __See__, R.L. Ritzman, et al., __*Surry Source Term and Consequence Analysis*__, Science Applications International Corporation, prepared for the Electric Power Research Institute, EPRI Report No. NP-4096, Final Report, June 1985, page 2-9. The NUREG-1150 analysis estimated the frequency of the V sequence at 9.0×10^{-7} per reactor-year. __See__, Robert C. Bertucio, et al., __*Analysis of Core Damage Frequency From Internal Events*__, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, page V-5.

containment failure. WASH-1400 estimated the frequency of sequence S_2C at 2×10^{-6} per reactor-year. 9/ 10/

Sequence S2D – Sequence S_2D represents a small LOCA in which the emergency coolant injection system fails. WASH-1400 estimated the frequency of sequence S_2D at 9×10^{-5} per reactor-year. 11/

Sequence S2H – Sequence S_2H represents a small LOCA in which the emergency coolant recirculation system fails. WASH-1400 estimated the frequency of sequence S_2H at 6×10^{-6} per reactor-year. 12/

9/ N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "Main Report," page 99.

10/ Both Science Applications International Corporation and the NUREG-1150 analyses conclude that this is a non-core melt sequence. See, R.L. Ritzman, et al., *Surry Source Term and Consequence Analysis*, Science Applications International Corporation, prepared for the Electric Power Research Institute, EPRI Report No. NP-4096, Final Report, June 1985, page 2-10; and Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, page V-70. The NUREG-1150 analysis identified similar sequences with medium and large LOCAs, loss of offsite power transients, and loss of feedwater transients as initiating events. These sequences were estimated to have an aggregate frequency of about 1.1×10^{-7} per reactor-year. See, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-69 to V-71. The large reduction in frequency arises from analyses which suggest that containment failure results in ECCS failure only 2% of the time, rather than 100% of the time as assumed in WASH-1400.

11/ The NUREG-1150 analysis estimated the frequency of this sequence at 7.1×10^{-7} per reactor-year. The analysis also estimated a similar sequence (resulting from reactor coolant pump seal LOCAs, which were not considered in WASH-1400) at 2.6×10^{-6} per reactor-year. See, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 to V-6.

12/ The NUREG-1150 analysis estimated the frequency of this sequence at 1.2×10^{-6} per reactor-year (sequences S_2H_1 and S_2H_2). See, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 to V-6.

__Sequence S1D__ -- Sequence S_1D represents a medium LOCA in which the emergency coolant injection system fails. WASH-1400 estimated the frequency of sequence S_1D at 3×10^{-6} per reactor-year. 13/ 14/

__Sequence S1H__ -- Sequence S_1H represents a medium LOCA in which the emergency coolant recirculation system fails. WASH-1400 estimated the frequency of sequence S_1H at 3×10^{-6} per reactor-year. 15/ 16/

__Sequence AD__ -- Sequence AD represents a large LOCA in which the emergency coolant injection system fails. WASH-1400 estimated the frequency of sequence AD at 2×10^{-6} per reactor-year. 17/ 18/

13/ N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 80.

14/ The NUREG-1150 analysis estimated the frequency of this sequence at 7.1×10^{-7} per reactor-year. __See__, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 to V-6.

15/ N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 80.

16/ The NUREG-1150 analysis estimated the frequency of this sequence at 7.7×10^{-7} per reactor-year. __See__, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 to V-6.

17/ N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 80.

18/ The NUREG-1150 analysis estimated the frequency of this sequence at 3.9×10^{-7} per reactor-year. __See__, Robert C. Bertucio, et al., *Analysis of Core Damage Frequency From Internal Events*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 to V-6.

<u>Sequence AH</u> -- Sequence AH represents a large LOCA in which the emergency coolant recirculation system fails. WASH-1400 estimated the frequency of sequence AH at 1 x 10^{-6} per reactor-year. <u>19</u>/ <u>20</u>/

<u>Sequence TKQ</u> -- Sequence TKQ represents a transient followed by failure of the reactor protection system and a failure of at least one pressurizer safety/relief valve to reclose. WASH-1400 estimate the frequency of sequence TKQ at 3 x 10^{-6} per reactor-year. <u>21</u>/ <u>22</u>/

<u>Sequence TKMQ</u> -- Sequence TKQ represents a loss of feedwater transient followed by failure of the reactor protection system and failure of at least one pressurizer safety/relief valve to reclose. WASH-1400 estimated the frequency of sequence TKMQ at 1 x 10^{-6} per reactor-year. <u>23</u>/ <u>24</u>/

<u>19</u>/ N.C. Rasmussen, et al., *<u>Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants</u>*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 80.

<u>20</u>/ The NUREG-1150 analysis estimated the frequency of this sequence at 3.9 x 10^{-7} per reactor-year. <u>See</u>, Robert C. Bertucio, et al., *<u>Analysis of Core Damage Frequency From Internal Events</u>*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, pages V-5 to V-6.

<u>21</u>/ N.C. Rasmussen, et al., *<u>Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants</u>*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 99.

<u>22</u>/ The NUREG-1150 analysis estimated the frequency of a similar sequence ($TKRD_4$) at 1.1 x 10^{-6} per reactor-year. <u>See</u>, Robert C. Bertucio, et al., *<u>Analysis of Core Damage Frequency From Internal Events</u>*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, page V-69.

<u>23</u>/ N.C. Rasmussen, et al., *<u>Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants</u>*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 99.

<u>24</u>/ The NUREG-1150 analysis estimated the frequency of a similar sequence (TKRZ) at 4.8 x 10^{-7} per reactor-year. <u>See</u>, Robert C. Bertucio, et al., *<u>Analysis of Core Damage Frequency From Internal Events</u>*, Sandia National Laboratories, prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-4550, SAND86-2084, Vol. 3, November 1986, page V-69.

ADDENDUM TO TABLE A
DOMINANT SURRY UNIT 1 ACCIDENT SEQUENCES, NUREG/CR-4550, VOL. 3

Table V.1-1
Surry Dominant Accident Sequences

Sequence	Frequency*	Plant Damage State
$T_1(SL)$-D_1CF_1	6.6E-6	SNNN
S_3D_1	2.6E-6	TYYB
$T_{23}Q$-H_1	1.9E-6	SYYB
$T_{1H}Q$-H_1	1.6E-6	SYYB
$T_1L(LT)D_1CF_1$	1.3E-6	TNNN
$T_1L(ST)D_1CF_1$	1.3E-6	TNNN
T_1LP	1.1E-6	TYYB
$TKRD_3$	1.1E-6	TYYB
EVENT-V	9.0E-7	EVENT-V
S_2H_1	8.9E-7	SYYB
$T_{23}Q$-H_2	8.1E-7	SYYB
S_1H_1	7.7E-7	AYYB
S_1D_1	7.1E-7	AYYB
S_2D_1	7.1E-7	SYYB
$T_{1H}Q$-H_2	6.3E-7	SYYB
TKRB	4.3E-7	SYYB
AD_2	3.9E-7	AYYB
AH_1	3.9E-7	AYYB
S_2H_2	3.3E-7	SYYB
T_1Q-D_1CF_1	3.2E-7	SNNN
$S_1F_1F_2$	7.0E-8	AYYB

* Point estimate based on propagation of mean values.

Table V.1-1 (Continued)
Surry Dominant Accident Sequences

Sequence	Frequency*	Plant Damage State
$S_2H_1F_1F_2$	5.0E-5	SYNI
$S_1H_1F_1F_2$	5.0E-5	AYNI
AF_1F_2	3.5E-8	AYNB
$AH_1F_1F_2$	2.5E-8	AYNI
$S_1D_6D_1C$	2.7E-9	ANNN
AD_6D_1C	1.4E-9	ANNN
$T_1LF_1F_2$	1.2E-8	TYNI
CORE DAMAGE TOTAL	2.5E-5	

* Point estimate based on propagation of mean values.

TABLE B **TO TESTIMONY OF STEVEN C. SHOLLY**

SURRY RELEASE CATEGORIES, WASH-1400

This exhibit provides a description of the WASH-1400 release categories for Surry Unit 1, as well as a table which gives the release characteristics (frequency, release magnitudes, etc.). Information for this Exhibit is taken from WASH-1400. 1/

1/ The release category frequencies and characteristics are taken from N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, "*Main Report*," page 97; the descriptions of the release categories are taken from N.C. Rasmussen, et al., *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, WASH-1400, NUREG-75/014, October 1975, Appendix VI, "*Calculation of Reactor Accident Consequences*," pages 2-1 to 2-3.

TABLE VI 2-1 SUMMARY OF ACCIDENTS INVOLVING CORE

2.2 ACCIDENT DESCRIPTIONS

To help the reader understand the postulated containment releases, this section presents brief descriptions of the various physical processes that define each release category. For more detailed information on the release categories and the techniques employed to compute the radioactive releases to the atmosphere, the reader is referred to Appendices I, VII, and VIII. The dominant event tree sequences in each release category are discussed in detail in section 4.6 of Appendix V.

PWR 1

This release category can be characterized by a core meltdown followed by a steam explosion on contact of molten fuel with the residual water in the reactor vessel. The containment spray and heat removal systems are also assumed to have failed and, therefore, the containment could be at a pressure above ambient at the time of the steam explosion. It is assumed that the steam explosion would rupture the upper portion of the reactor vessel and breach the containment barrier, with the result that a substantial amount of radioactivity might be released from the containment in a puff over a period of about 10 minutes. Due to the sweeping action of gases generated during containment-vessel meltthrough, the release of radioactive materials would continue at a relatively low rate thereafter. The total release would contain approximately 70% of the iodines and 40% of the alkali metals present in the core at the time of release.[1] Because the containment would contain hot pressurized gases at the time of failure, a relatively high release rate of sensible energy from the containment could be associated with this category. This category also includes certain potential accident sequences that would involve the occurrence of core melting and a steam explosion after containment rupture due to overpressure. In these sequences, the rate of energy release would be lower, although still relatively high.

PWR 2

This category is associated with the failure of core-cooling systems and core melting concurrent with the failure of containment spray and heat-removal systems. Failure of the containment barrier would occur through overpressure, causing a substantial fraction of the containment atmosphere to be released in a puff over a period of about 30 minutes. Due to the sweeping action of gases generated during containment vessel meltthrough, the release of radioactive material would continue at a relatively low rate thereafter. The total release would contain approximately 70% of the iodines and 50% of the alkali metals present in the core at the time of release. As in PWR release category 1, the high temperature and pressure within containment at the time of containment failure would result in a relatively high release rate of sensible energy from the containment.

PWR 3

This category involves an overpressure failure of the containment due to failure of containment heat removal. Containment failure would occur prior to the commencement of core melting. Core melting then would cause radioactive materials to be released through a ruptured containment barrier. Approximately 20% of the iodines and 20% of the alkali metals present in the core at the time of release would be released to the atmosphere. Most of the release would occur over a period of about 1.5 hours. The release of radioactive material from containment would be caused by the sweeping action of gases generated by the reaction of the molten fuel with concrete. Since these gases would be initially heated by contact with the melt, the rate of sensible energy release to the atmosphere would be moderately high.

PWR 4

This category involves failure of the core-cooling system and the containment spray injection system after a loss-of-coolant accident, together with a concurrent failure of the containment system to properly isolate. This would result in the release of 9% of the iodines and 4% of the alkali metals present in the core at the time of release. Most of the release would occur continuously over a period of 2 to 3 hours. Because the containment recirculation spray and heat-removal systems would operate to remove heat from the containment atmosphere during core melting, a relatively low rate of release of sensible energy would be associated with this category.

PWR 5

This category involves failure of the core cooling systems and is similar to PWR release category 4, except that the containment spray injection system would operate to further reduce the quantity of airborne radioactive material and to initially suppress containment temperature and pressure. The containment barrier would have a large leakage rate due to a concurrent failure of the containment system to properly isolate, and most of the radioactive material would be released continuously over a period of several hours. Approximately 3% of the iodines and 0.9% of the alkali metals present in the core would be released. Because of the operation of the containment heat-removal systems, the energy release rate would be low.

PWR 6

This category involves a core meltdown due to failure in the core cooling systems. The containment sprays would not operate, but the containment barrier would retain its integrity until the molten core proceeded to melt through the concrete containment base mat. The radioactive materials would be released into the ground, with some leakage to the atmosphere occurring upward through the ground. Direct leakage to the atmosphere would also occur at a low rate prior to containment-vessel meltthrough. Most of the release would occur continuously over a period of about 10 hours. The release would include approximately 0.08% of the iodines and alkali metals present in the core at the time of release. Because leakage from containment to the atmosphere would be low and gases escaping through the ground would be cooled by contact with the soil, the energy release rate would be very low.

PWR 7

This category is similar to PWR release category 6, except that containment sprays would operate to reduce the containment temperature and pressure as well as the amount of airborne radioactivity. The release would involve 0.002% of the iodines and 0.001% of the alkali metals present in the core at the time of release. Most of the release would occur over a period of 10 hours. As in PWR release category 6, the energy release rate would be very low.

PWR 8

This category approximates a PWR design basis accident (large pipe break), except that the containment would fail to isolate properly on demand. The other engineered safeguards are assumed to function properly. The core would not melt. The release would involve approximately 0.01% of the iodines and 0.05% of the alkali metals. Most of the release would occur in the 0.5-hour period during which containment pressure would be above ambient. Because containment sprays would operate and core melting would not occur, the energy release rate would also be low.

PWR 9

This category approximates a PWR design basis accident (large pipe break), in which only the activity initially contained within the gap between the fuel pellet and cladding would be released into the containment. The core would not melt. It is assumed that the minimum required engineered safeguards would function satisfactorily to remove heat from the core and containment. The release would occur over the 0.5-hour period during which the containment pressure would be above ambient. Approximately 0.00001% of the iodines and 0.000006% of the alkali metals would be released. As in PWR release category 8, the energy release rate would be very low.

~~PWR 1~~

~~This release category is representative of a core meltdown followed by a steam explosion in the reactor vessel. The latter would cause the release of a substantial quantity of radioactive material to the atmosphere. The total release would contain approximately 40% of the iodines and alkali metals present in the core at the time of containment failure. Most of the release would occur over a 2-hour period. Because of the energy generated in the steam explosion, this category would be characterized by a relatively high rate of energy release to the atmosphere. This category also includes certain sequences that involve overpressure failure of the containment prior to the occurrence of core melting and a steam explosion. In these sequences, the rate of energy release would somewhat smaller than for those discussed above, although it would still be relatively high.~~

TABLE C TO TESTIMONY OF STEVEN C. SHOLLY

FIGURES I-11 TO I-18, NUREG-0396

This exhibit consists of reproduced pages from NUREG-0396 containing Figures I-11 through I-16. These figures are reproduced on the following six pages.

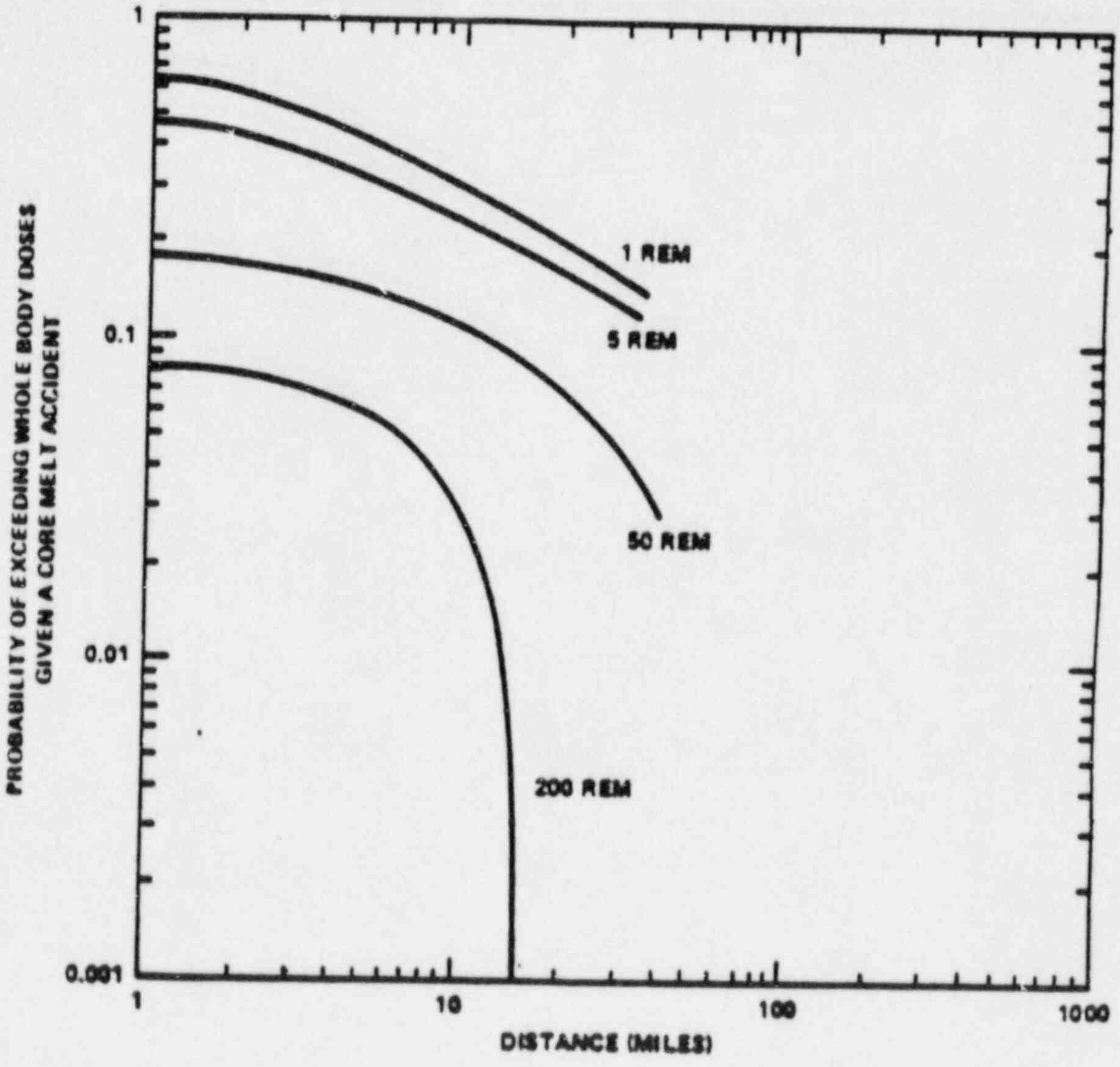


Figure I-11. Conditional Probability of Exceeding Whole Body Dose Versus Distance. Probabilities are Conditional on a Core Melt Accident (5×10^{-5}).

Whole body dose calculated includes: external dose to the whole body, due to the passing cloud, exposure to radionuclides on ground, and the dose to the whole body from inhaled radionuclides.

Dose calculations assumed no protective actions taken, and straight line plume trajectory.

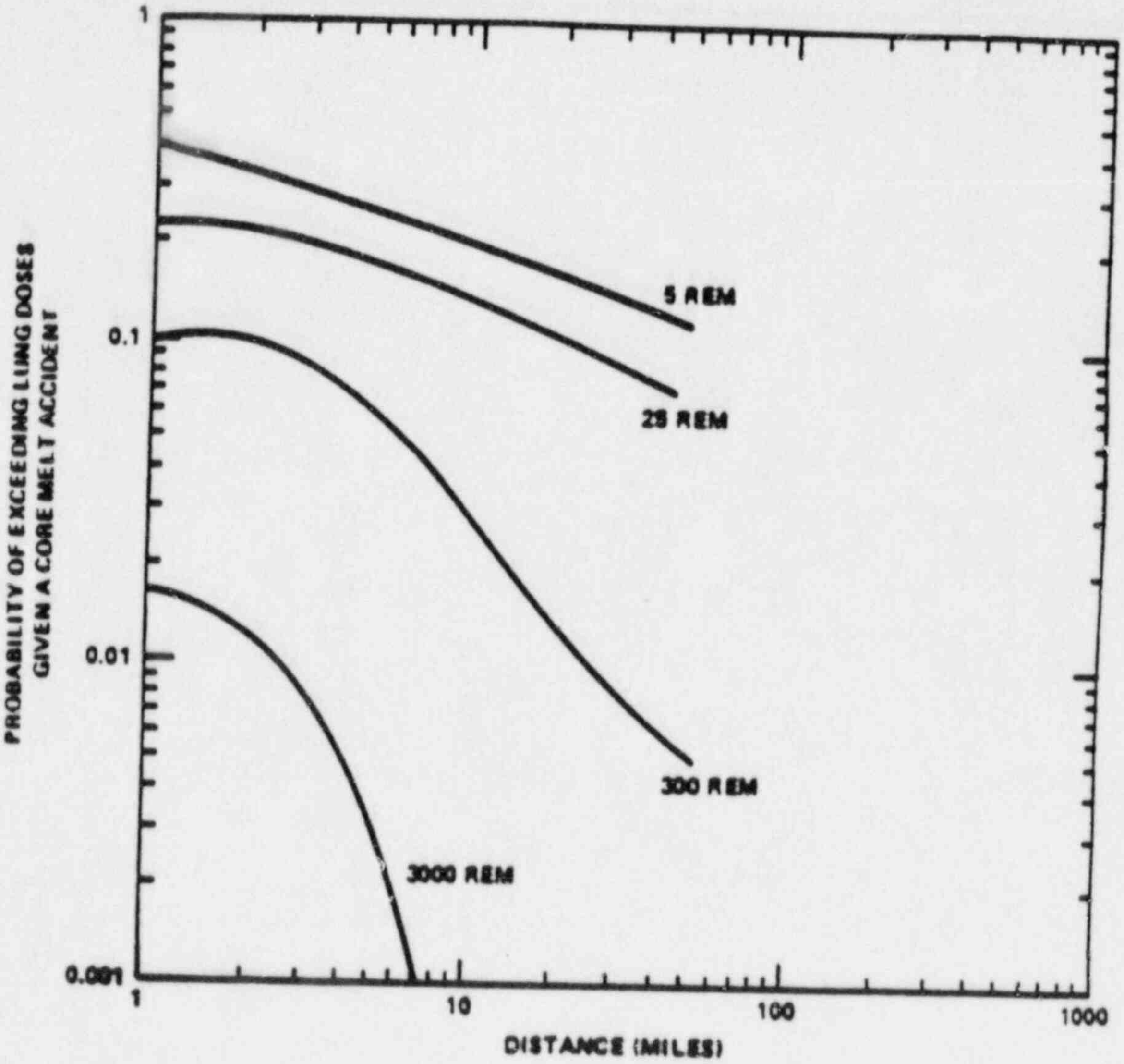


Figure I-12. Conditional Probability of Exceeding Lung Doses Versus Distance. Probabilities are Conditional on a Core Melt Accident (5×10^{-5}).

Lung dose calculated includes: external dose to the lung due to the passing cloud, exposure to radionuclides on ground, and the dose to the lung from inhaled radionuclides within 1 year.

Dose calculations assumed no protective actions taken, and straight line trajectory.

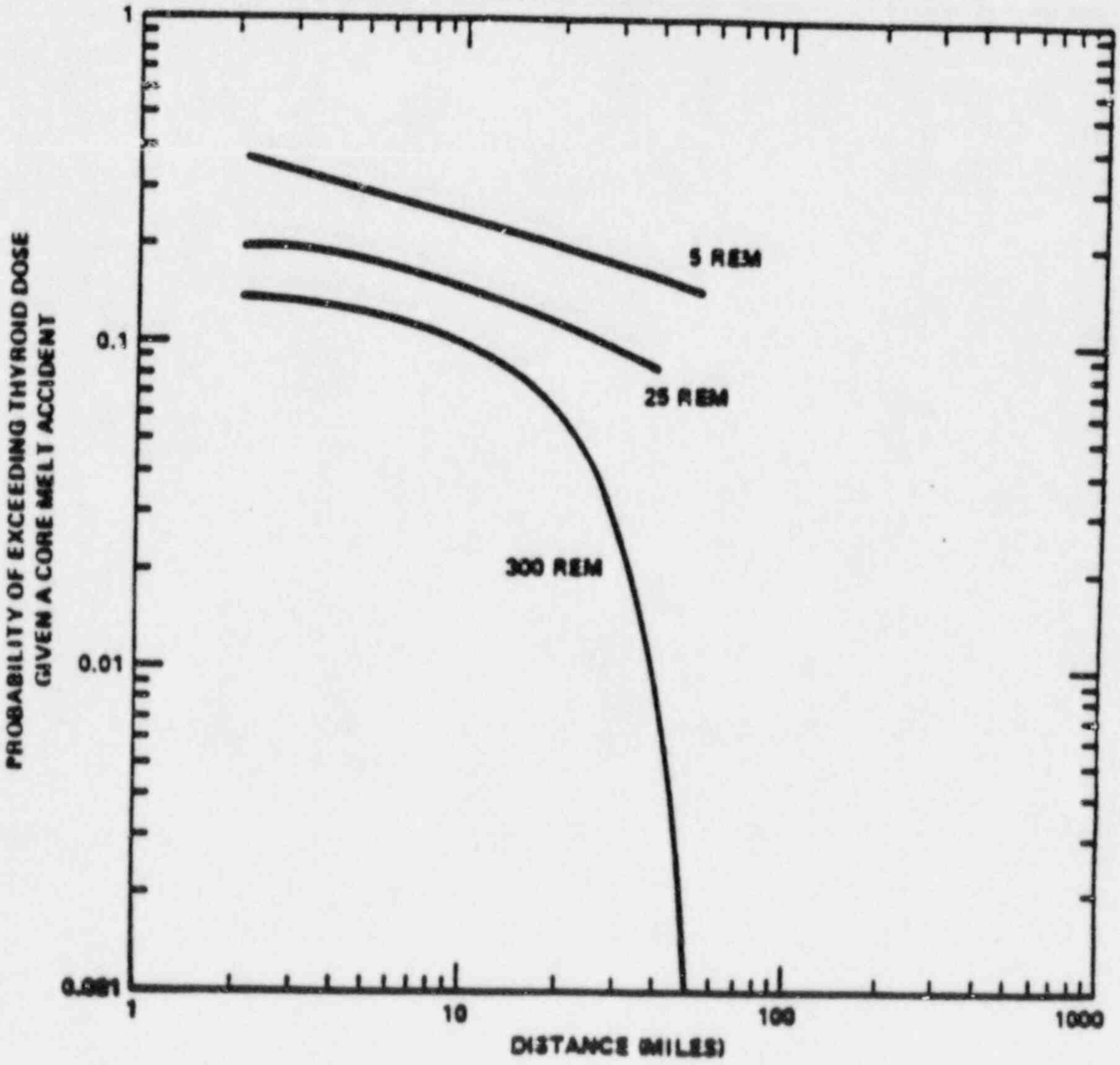


Figure I-13. Conditional Probability of Exceeding Thyroid Doses Versus Distance. Probabilities are Conditional on a Core Melt Accident (5×10^{-5}).

Thyroid dose calculated includes: external dose to the thyroid due to the passing cloud, exposure to radionuclides on ground, and the dose to the thyroid from inhaled radionuclides.

Dose calculations assumed no protective actions taken, and straight line trajectory.

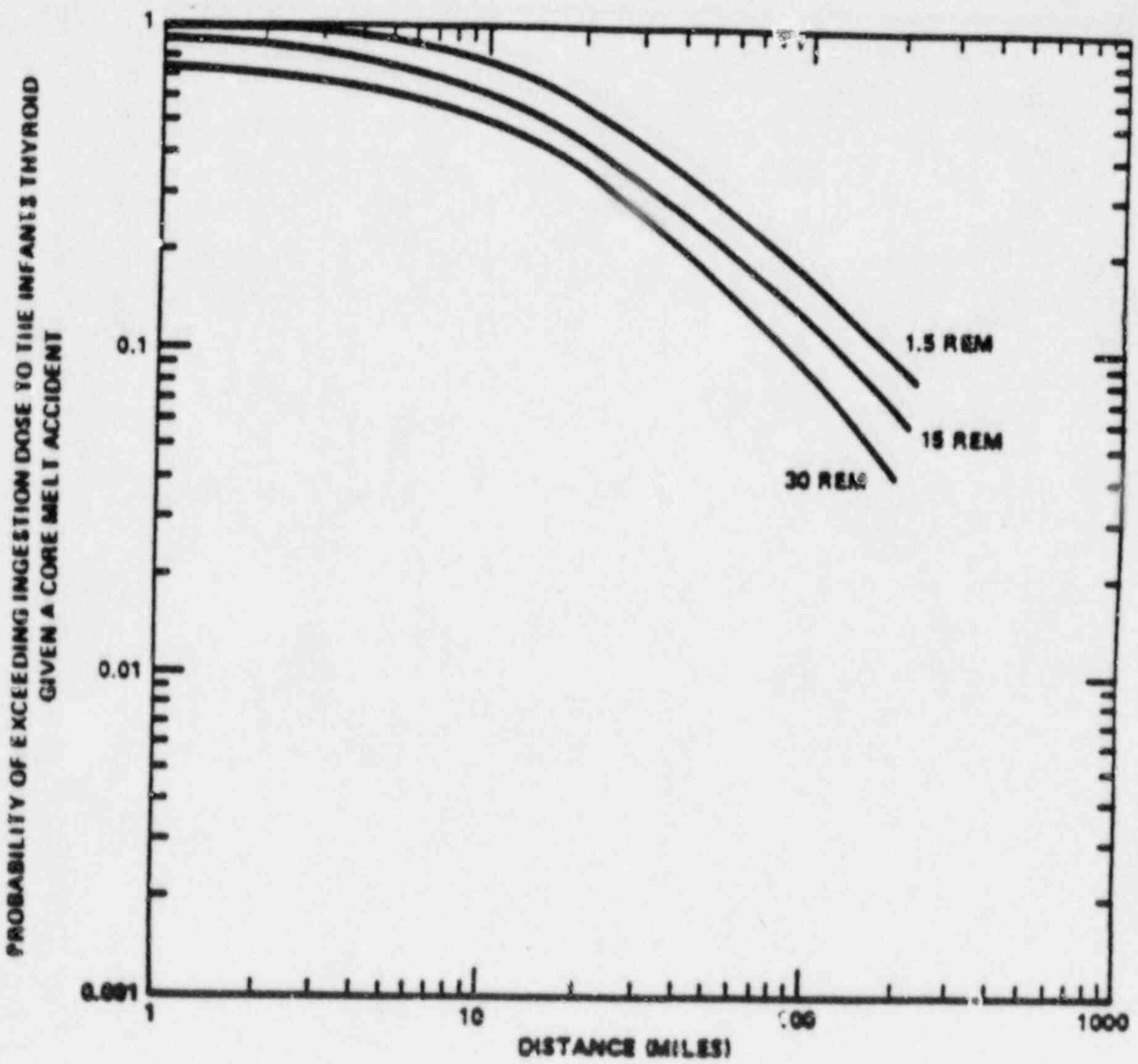
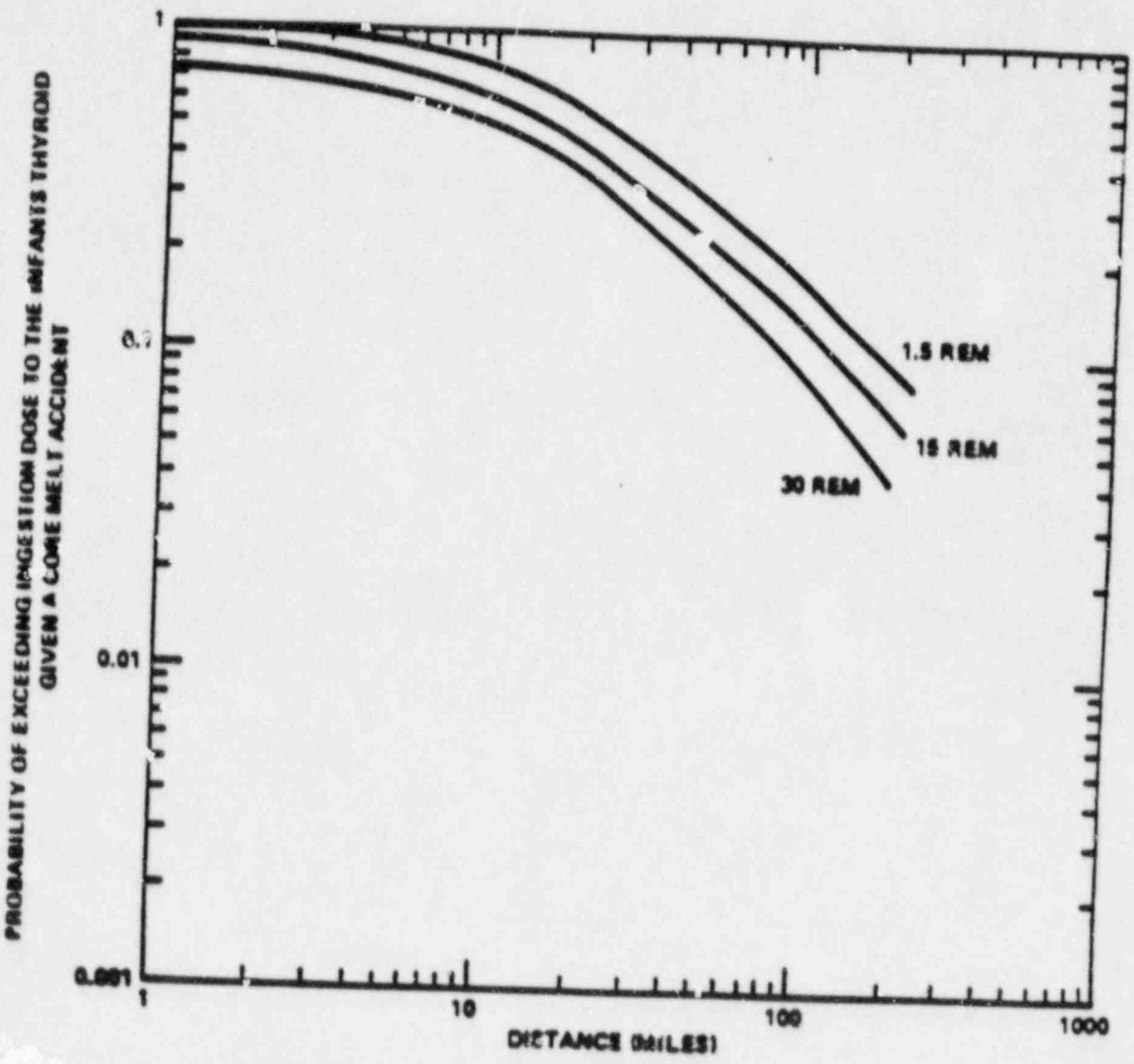


Figure I-14. Conditional Probability of Exceeding Thyroid Dose to an Infant Versus Distance. Probabilities are Conditional on a Core Melt Accident (5×10^{-5}).

Thyroid dose calculated is due solely to radionuclide ingestion through the milk consumption pathway.

Dose calculations assumed no protective actions taken, and straight line trajectory.



[illegible]re I-14. [illegible]nal Probability of Exceeding Thyroid Dose to an Infant Versus Distance. [illegible]ties are Conditional on a Core Melt Accident (5×10^{-5}).
[illegible] dose calculated is due solely to radionuclide ingestion through the milk [illegible]tion pathway.
[illegible] calculations assumes no protective actions taken, and straight line trajectory.

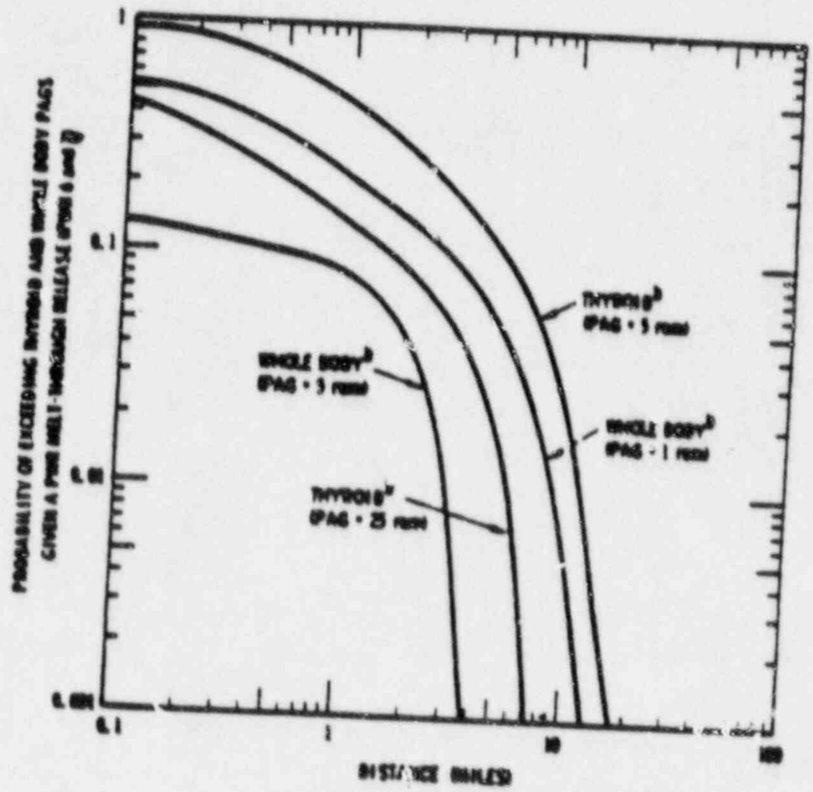


Figure 5-5[illegible]. Conditional Probability of Exceeding Thyroid and Whole Body Protective Action Guides (PAGs) Versus Distance for an Individual [illegible] [illegible]. Probabilities are Conditional on a PWR "Melt-Through" Release (PWR 6 and 7).

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

[b]Whole body [illegible] dose equivalent includes external dose to the whole body [illegible] due to the passing cloud and 1-day exposure to radionuclides on ground, and the dose to the whole body [illegible] from inhaled radionuclides within 1 year.

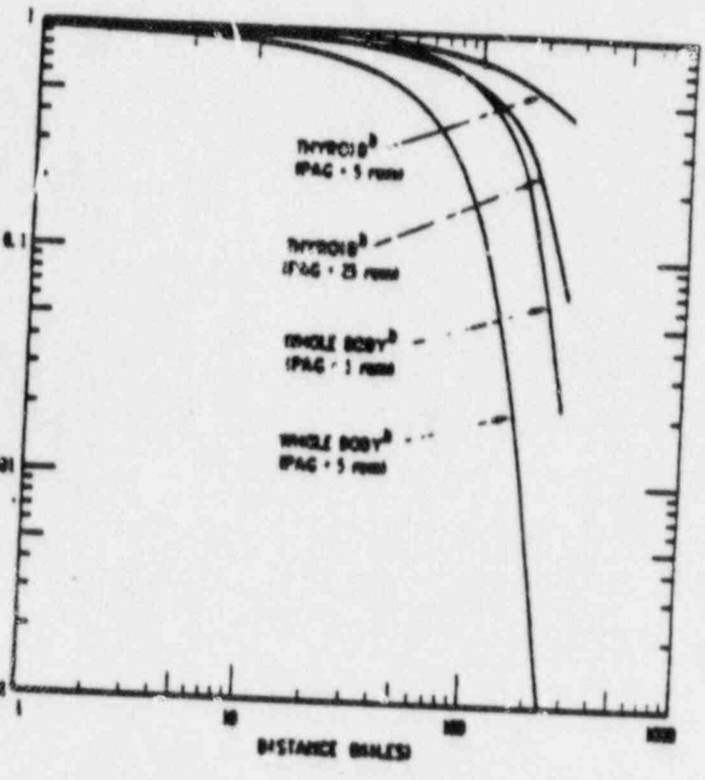


Figure I-16. [illegible] Probability of [illegible] Thyroid and Whole Body Protective Action Guides (PAGs) Versus Distance for an Individual Located Outdoors.[a] Probabilities are [illegible] on a PWR "Atmospheric" Release (Ref I-5).

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

[b]Whole body [illegible] variables: external dose to the whole body [illegible] due to the passing cloud and 1-day exposure to radionuclides on ground, and the dose to the whole body [illegible] from inhaled radionuclides within 1 year.

TABLE D TO TESTIMONY OF STEVEN C. SHOLLY

FIGURE 6.1 FROM MARCH 1987 BNL REPORT

This Exhibit consists of Figure 6.1 from W.T. Pratt & C. Hofmayer, et al., *Technical Evaluation of the EPZ Sensitivity Study for Seabrook*, Brookhaven National Laboratory, prepared for the U.S. Nuclear Regulatory Commission, March 1987, page 6-19. This figure can be compared with Figure I-11 from NUREG-0396 (see, Exhibit 5, attached to this testimony).

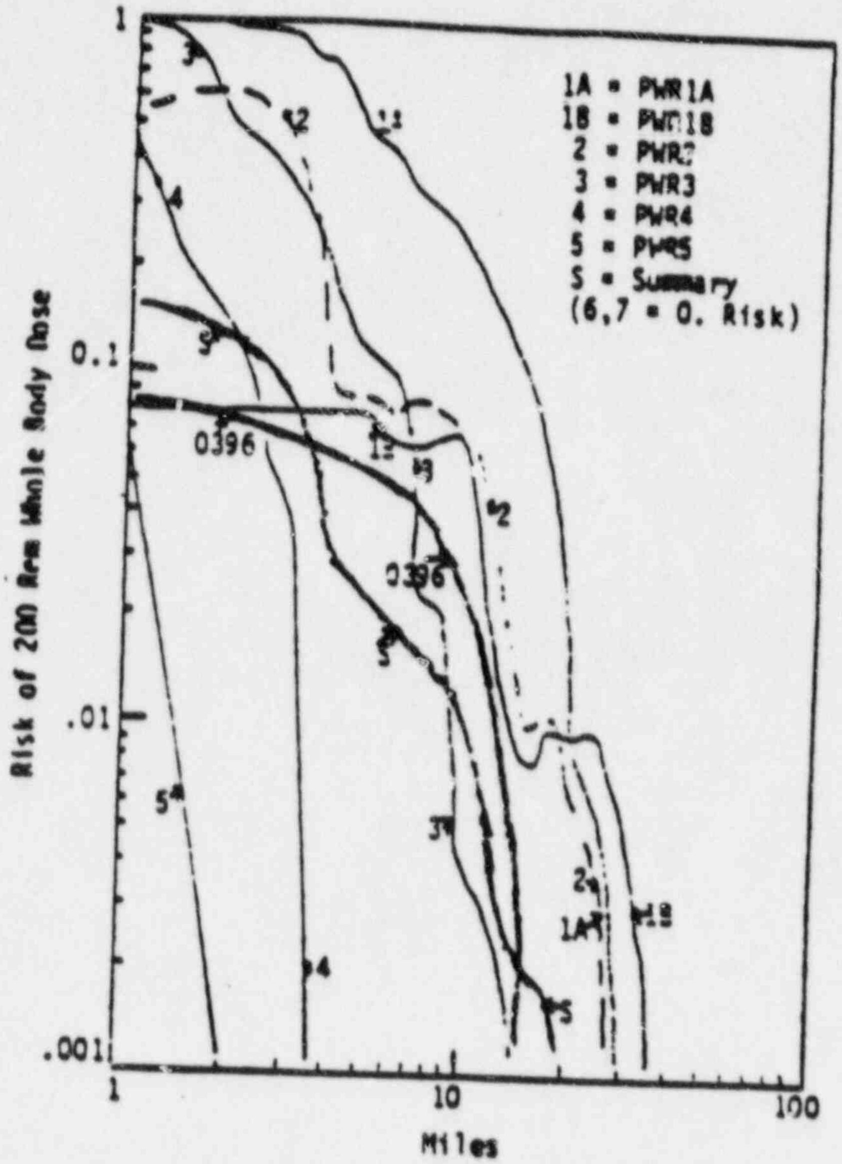


Figure 6.1 Components of NUREG-0396 curve as computed by BNL using CRAC2. The summary curve is normalized to $6x10^{-5}$ core melt probability. The result differs from NUREG-0396.

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B. John Garrick (Study Director) et al., Seabrook Station Probabilistic Safety Assessment, Pickard, Lowe and Garrick Inc., prepared for Public Service Company of New Hampshire and

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