UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before the Atomic Safety and Licensing Board

In the Matter of	)	
	)	
LONG ISLAND LIGHTING COMPANY	)	Docket No. 50-322 (OL)
	)	(Emergency Planning--
(Shoreham Nuclear Power Station, Unit 1)	)	Phase I)
	)	

TESTIMONY OF H. MARK BLAUER, MATTHEW C. CORDARO, AND JOHN F. SCHMITT FOR THE LONG ISLAND LIGHTING COMPANY ON PHASE I EMERGENCY PLANNING CONTENTION 10(B) -- REAL TIME MONITORS

PURPOSE

The purpose of this testimony is to establish that the equipment LILCO intends to use to monitor releases provides information regarding radioiodine, particulate and noble gas releases to the environment. Downwind survey teams can scan for the plume centerline and the plume boundary and determine atmospheric radioiodine concentrations. The REMP can collect specific media in each portion of the aquatic, terrestrial and atmospheric environment including direct accumulated radiation dosimetry using TLD's. Together, these systems, equipment, and methods provide timely, accurate, and detailed information for predicting and calculating dose assessment. Thus, LILCO has

the ability to assess accidents and monitor radiological releases from the Shoreham facility in the event of a radiological emergency. Real time monitors are not required by NRC regulations and guidelines, and are unnecesary for timely monitoring of the plume.

Attachments to this Testimony:

Attachment 10(B)-1	Professional Qualifications of H. Mark Blauer
Attachment 10(B)-2	Professional Qualifications of Matthew C. Cordaro
Attachment 10(B)-3	Professional Qualifications of John F. Schmitt
Attachment 10(B)-4	SECY 82-111, "NRC Staff Recommendations on the Requirements for Emergency Response Capability"
Attachment 10(B)-5	NUREG/CR-2644, "An Assessment of Offsite Real Time Dose Measurement Systems for Emergency Situations"
Attachment 10(B)-6	SP 69.026.01, "Protective Action Recommendations"
Attachment 10(B)-7	AIF/NESP-023, "Evaluation of an Environs Exposure Rate Monitoring System for Post-Accident Assessment"

LILCO, October 12, 1982

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Q1. Please state your names and business addresses.

A2. [Blauer] My name is H. Mark Blauer; my address is 175 Old Country Road, Hicksville, New York, 11801.

[Cordaro] My name is Matthew C. Cordaro; my address is 175 Old Country Road, Hicksville, New York, 11801.

[Schmitt] My name is John F. Schmitt; my address is Shoreham Nuclear Power Station, P. O. Box 628, Wading River, New York, 11792.

Q2. What are your positions with LILCO?

A2. [Blauer] I am Emergency Planning Coordinator and Chairman of the Emergency Planning Task Force.

[Cordaro] I am Vice President, Engineering for LILCO.

[Schmitt] I am the Radiochemistry Engineer at Shoreham.

Q3. Please state your professional qualifications.

A3. [Blauer] My professional qualifications are attached to this testimony (Attachment 10(B)-1). My familiarity with the issues surrounding the use of real time monitors stems from research in conjunction with my teaching position, and my duties involving specification and installation of real time monitors during the course of employment in various positions.

[Cordaro] My professional qualifications are attached to this testimony (Attachment 10(B)-2). I am sitting with this panel to provide the LILCO management perspective regarding Emergency Planning, and to answer any questions pertinent to management. My role in Emergency Planning is to ensure that the needs and requirements of Emergency Planning are being provided, and that the technical direction and content of Emergency Planning are being conveyed to corporate management.

[Schmitt] My professional qualifications are attached to this testimony (Attachment 10(B)-3). My familiarity

with the issues surrounding the use of real time monitors stems from my familiarity with the Radiation Monitoring System, and the effluent qualification and dose calculation methods we employ.

Q4. Are you familiar with Suffolk County Contention EP 10(B)?

A4. [Blauer, Cordaro, Schmitt] Yes.

Q5. What does that contention say?

A5. [Blauer, Cordaro Schmitt] EP 10(B) provides:

> Suffolk County contends that the LILCO plan (See Chapter 6) is inadequate with respect to its ability to assess and mitigate accidents and monitor radiological releases from the Shoreham facility in the event of a radiological emergency. Thus, LILCO has failed to comply with 10 C.F.R. §§ 50.47(b)(2), (4), (8), (9), and (10), 10 C.F.R. Part 50, Appendix E and NUREG 0654, Items II.B, D, H, I, and J in the following respects:
>
> (B) LILCO does not intend to use real time monitors at fixed locations that can be remotely interrogated.

Q6. Are you familiar with the regulatory requirements and guidelines cited in the preamble to EP 10(B)?

A6. [Blauer, Schmitt] Yes.

Q7. Are all of the regulations cited by the County applicable to the issue of real time monitors?

A7. [Blauer, Schmitt] Arguably, 10 C.F.R. § 50.47(b)(9), 10 C.F.R. 9 50, Appendix E, Item IV.E, and NUREG-0654, Items II.H(6)(b) and I(8) are related to the issues surrounding real time monitors.

Q8. What do those regulations and guidelines say?

A8. [Blauer, Schmitt] 10 C.F.R. § 50.47(b)(9) provides:

> Adequate methods, systems and equipment for assessing and monitoring actual or potential offsite consequences of a radiological emergency condition are in use.

10 C.F.R. Part 50 Appendix E, Item IV.E(2) provides:

> Adequate provisions shall be made and described for emergency facilities and equipment including: . . . (2) equipment for determining the magnitude of and for continuously assessing the impact of the release of radioactive materials to the environment.

NUREG-0654, Item II.H(6)(b) provides:

> Each licensee shall make provisions to acquire data from or for emergency access to offsite monitoring and analysis equipment including: . . . (b) radiological monitors including rate meters and sampling devices. Dosimetry shall be provided and shall meet at a minimum the radiological assessment branch technical position for the environmental radiological monitoring program.

NUREG-0654, Item II.I(8) provides:

> Each organization [licensee, state and local], where appropriate, shall provide methods, equipment and expertise to make rapid assessment of the actual or potential magnitude and locations of any radiological hazards through liquid or gaseous release pathways. This shall include activation,

notification means, field team composition, transportation, communication, monitoring equipment and estimated deployment times.

Q9. Do the regulatory requirements and guidelines cited by the County, or any other requirements or guidelines, require LILCO to install real time monitors?

A9. [Blauer] No. In SECY 82-111, "NRC Staff Recommendations on the Requirements for Emergency Response Capability" (Attachment 10(B)-4 to this testimony), the NRC Staff states at part 2.A on page 13 that "continuous offsite dose monitors are not required pending their further development and consideration as requirements." In addition, NUREG/CR-2644, "An Assessment of Offsite Real Time Dose Measurement Systems for Emergency Situations" (Attachment 10(B)-5 to this testimony) summarizes that "in general it is highly questionable that a 16-32 unit emergency monitoring system can provide sufficiently reliable technical information to be of use in a decision making process in the event of an emergency situation." Real time monitoring capability is not recommended by NUREG-0654, Rev. 1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants." The schedule for implementing the use of 16-20 environs

radioactivity monitors in the proposed revision to Reg. Guide 1.97, "Instrumentation for Light Water Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident", dated December 19, 1979, has been delayed in Revision 2 to Reg. Guide 1.97, dated December 1980. (errata, July 1981).

Q10. What are real time monitors?

A10. [Blauer] An offsite dose measurement system (real time monitor system) consists of fixed field stations comprised of (1) a detection device (the real time monitor) and (2) a microprocessor with data transmission capability. The detection device, normally a pressurized ionization chamber, and associated electronics, such as preamplifiers, amplifiers, high voltage supplies and other equipment, measure real time dose rates. The microprocessor converts the field detection data to output data for transmission by either radio telemetry, dedicated phone line, or hard wire connection to a remotely located, central processing unit (CPU). The CPU acquires, reduces, and stores data describing radiation dose rate conditions existing at each field station.

Q11. Does LILCO plan to install real time monitors?

A11. [Blauer, Schmitt] No.

Q12. Why not?

A12. [Blauer, Schmitt] LILCO does not intend to use real time monitors because (1) LILCO has in-plant monitors that monitor radiation releases, and field teams that monitor the plume, making real time monitors unnecessary, and (2) there are certain functions that cannot be performed by a real time monitor that can be performed by LILCO field monitoring teams.

Q13. How does LILCO monitor releases and assess doses?

A13. [Blauer, Schmitt] LILCO uses three methods to monitor releases and assess doses:

(1) Radiation Monitoring System;
(2) field monitoring teams; and
(3) Radiological Environmental Monitoring Program.

Q14. What is the Radiation Monitoring System?

A14. [Blauer, Schmitt] The Radiation Monitoring System (RMS) is a computer-based system that provides the status of radiation levels throughout the plant to the control room operators. The data from radiation

monitors are inputted to the computer to provide continuous real time data on plant conditions. These data are stored as an historical file for report generation. Set points are provided for each radiation monitor and automatically trip to alert plant personnel of unusual conditions.

In addition to keeping the staff aware of conditions in the plant, the RMS performs calculations to determine the effect of effluents on the population. For gaseous releases, the RMS uses radiation detector readings at the point of discharge, with current meteorological data from the offsite meteorological tower instruments. These data are used in the accident situation in formulas concerning dispersion and biological effect of each radionuclide in the release. Using the data, the RMS calculates radiation doses to the thyroid and whole body to individuals at various distances in the downwind direction from the plant.

Q15. What is the Radiological Environmental Monitoring Program?

A15. [Blauer] The Radiological Environmental Monitoring Program (REMP) identifies and determines the background radioactivity present in various biological, hydrological, lithological, and atmospheric media found in the

Shoreham environs. Samples of these media are chosen for monitoring to best determine the radioactivity present in pathways to humans. The samples are sensitive indicators of changes in radioactive levels. Results from analyses of these samples will indicate any environmental impact Shoreham may cause.

Media sampled within the aquatic environment include surface water, aquatic plants, fish, invertebrates and sediment. From the atmospheric environment, airborne particulates and iodine are collected. From the terrestrial environment, milk, potable water, food products, game and soil are obtained. In addition, direct accumulated radiation doses are measured using thermoluminescent dosimeters (TLD). During an emergency, the REMP can be increased in size, scope and frequency of sample collection.

Emergency response capabilities to analyze these samples within approximately 24 hours have been established. Thus, the REMP can provide a historical record to monitor releases and assess doses.

Q16. What is the composition of the field monitoring teams?

A16. [Blauer] Should an offsite radiological release occur, LILCO has the capability to dispatch three field

monitoring teams. Each team would consist of a health physics/engineering technician and a health physics/engineering aide. Depending upon the level of emergency declaration and the emergency response facility that has been activated, the team will be dispatched either from the Technical Support Center (TSC) or the Emergency Operations Facility (EOF).

Field teams are dispatched to measure offsite radiation levels. Each team is issued a downwind survey kit, a portable two-way radio, and a field monitoring vehicle. Included in each kit are:

(1) a portable dose rate survey meter;
(2) a portable high volume air sampler;
(3) a portable count rate meter;
(4) personal dosimeters;
(5) respiration equipment;
(6) protective clothing; and
(7) potassium iodide pills.

Q17. What is a portable dose rate survey meter?

A17. [Blauer] A portable dose rate survey meter measures radiation levels. It is a hand-held box, about the size of a small shoe box, with a probe attached by coaxial cable. The portable dose rate survey meter can

be used to determine the location of the plume by comparing (1) the dose rate shown when the probe is held four feet above the ground and pointed to the sky to (2) the dose rate shown when the probe is held three inches off the ground and pointed toward the ground. The field monitoring teams can compare the two dose rates to determine whether the plume is above them, has settled on the ground, or is around them. In addition, by scanning with the portable dose rate survey meter as the field teams are traveling through an area, the field teams can locate the plume boundaries and centerline.

Q18. What is the portable high volume air sampler?

A18. [Blauer, Schmitt] A portable high volume air sampler is a large box that has the ability to suck air through a filter-cannister assembly, and exhaust the air through to the other side. Particulate radioactive material that may be in the atmosphere is deposited on the filter, and radioiodine is collected on silver-impregnated resin located behind the filter. The cartridge containing the filter and the resin can then be removed from the air sampler and taken to the field monitoring vehicle, where instruments are available to analyze the sample deposited in the cartridge and on

the filter. The results of these analyses are reported by the field monitoring team to the dose assessment staff, using two-way radios. The dose assessment staff uses that information in their dose assessment calculation, using the dose assessment model described in the testimony filed for emergency planning contention 14.

Q19. What is a portable count rate meter?

A19. [Blauer] The count rate meter is similar to the dose rate survey meter, but measures the quantity of radioisotopes in the environment. It uses a compensated GM detector. The count rate meter is used to determine the amount of radioactive material collected in an air sample. The portable count rate meter enables the field monitoring teams to determine the particulate and radioiodine concentrations in the plume. The portable count rate meter and GM detector, when used with the TCS high volume air sampler, is capable of detecting as little as 10^{-7} uCi/cc I-131.

Q20. How are personal dosimeters, respiration equipment, and protective clothing used?

A20. [Blauer] These items allow the field monitoring teams to travel throughout the ten-mile EPZ to monitor the plume, while maintaining doses as low as reasonably achievable (ALARA).

Q21. How is the information obtained from the Radiation Monitoring System, the field monitoring teams, and the Radiological Environmental Monitoring Program used by LILCO in radiological assessment?

A21. [Blauer, Schmitt] The Radiation Monitoring System provides release rates, source terms, and concentrations of effluent releases. During accident situations, real time site meteorology is used with emergency dose software to calculate offsite doses. These calculated projected doses are used in accordance with SP 69.026.01, "Protective Action Recommendations" (Attachment 10(B)-6 to this testimony), to determine the appropriate recommendation.

Downwind survey teams provide actual radiation measurements of dose rate, particulate, and radioiodine air concentrations. These measurements are transmitted by radio to the dose assessment staff for determination of measured projected doses. The survey teams provide more accurate and reliable measurements than the Radiation Monitoring System for determining protective action recommendations, and can verify projected doses from the Radiation Monitoring System.

The Radiological Environmental Monitoring Program allows for the collection and analyses of environmental

samples. These results provide an historical record to be used in assessing the radiological environmental impact of an accident.

Q22. What is the capability of a real time monitoring system?

A22. [Blauer] A real time monitoring system features continuous monitoring of ambient radiation levels, continuous 24-hour opertion, and remote interrogation from any number of locations.

Q23. Did LILCO consider using a real time monitoring system as part of its emergency plan?

A23. [Blauer] Yes. The Emergency Planning Task Force investigated the merits of a real time system to determine offsite doses by field monitoring and telemetering field readouts to the plant control room and the emergency response facilities. The Emergency Planning Task Force concluded that such a system would not sufficiently enhance LILCO's present monitoring capabilities to an extent that would justify the expense, because of the following:

(1) The present Radiation Monitoring System already calculates dose and dose rate values using real time meterclogical information for the downwind

sector, from the exclusion area out to a distance of 100 kilometers from the plant, based on current accident or sampled isotopic releases.

(2) The RMS can also display on a Long Island map all areas having the potential for dose or dose rate values equal to or greater than protective action guidelines.

(3) Remote real time systems cannot reasonably determine isotopic concentrations and may not, in most cases, be in the plume path. Additionally, remote real time systems are not sufficiently sensitive to provide timely indications of actual public dose.

(4) Downwind survey teams can more accurately define the plume and sample the environmental radioactivity. Actual samples can be taken and analyzed. If one of the existing environmental stations is located in the plume pathway, its monitors and samples can also be used.

Q24. Are there any other limits to the real time monitoring system that the County proposes LILCO use?

A24. [Blauer] Yes. Calibration of the overall real time monitoring system is extensive. The detectors and

electronics, as an integrated system for each field station, must be calibrated to obtain conversion factors relating detector current to dose rate (R/hr). Report AIF/NESP-023, "Evaluation of an Environs Exposure Rate Monitoring System for Post Accident Assessment" (Attachment 10(B)-7 to this testimony), states that the initial calibration energy range for detectors should be from 60 to 3,000 keV. Also, the initial detector calibration from the system vendor should be done at the National Bureau of Standards (NBS) or with an air cavity ionization chamber calibrated by the NBS. Less extensive field calibration, that is, use of fewer energies, should be conducted semi-annually.

In addition, a real time monitoring system would give no indication of an impending release, and hence would not provide warning time to initiate protective action. The monitors must be located close to the plant, preferably within one mile, to provide the sensitivity and response time necessary for predicting and calculating doses. Under certain meteorological conditions during a nuclear incident, the plume may rise and skip over the detectors. Therefore, the real time monitors would not enhance LILCO's capabilities to determine onsite and offsite doses.

Furthermore, sixteen locations (one for each sector for a 360 degree planning area around the plant) do not provide any precise information regarding the plume's centerline or plume boundary. As I previously mentioned, downwind survey teams are able to scan for the plume centerline and the plume boundary, providing more accurate and detailed information for predicting and calculating doses. The equipment LILCO will use to monitor the plant effluent releases provides timely and accurate information regarding actual quantities of radioactive iodine, particulate, and noble gas releases to the environment.

The real time monitoring system's potential deficiencies are summarized aptly in NUREG-CR-2644 as follows:

(1) While a ring of detectors around a nuclear power station can provide the means for monitoring releases, the number of stations required for two detectors to provide information within a factor of five of each other can be as large as 50 or more for one installation.

(2) The use of short time (15 minutes) data from a fixed offsite monitoring system to project downwind dose rates is a complex and highly uncertain process. Based on our study, the uncertainty associated with a projected value is at least a factor of 10 or more.

(3) The use of a fixed offsite monitoring system to determine the magnitude of an unmonitored release in the presence of a monitored release is highly questionable. Depending on the ratio of an unmonitored

release to the monitored release, uncertainties of factors of 25 and 50 are common.

(4) Several vendors of monitoring equipment were contacted relative to cost and performance characteristics of the available instrumentation. In addition, we contacted several power stations and state agencies involved in the installation of fixed real time environmental monitoring systems. While the cost factors for the instrumentation were relatively fixed, the installation costs were highly variable. Based on this study, the cost per monitoring station ranges from $25,000 to $65,000. Depending upon the specific site characteristics, the cost for a 32 station system could easily exceed $1,000,000 while only providing data with uncertainties in the range of factors 10 to 50.

(5) The placement of the simple limited ($500,000) detector system in proximity (0.5 miles) to a reactor may not provide reliable information in the case of an emergency for several reasons. Of prime importance is the limited number of stations (8-16) that could be installed and the consequence that a plume might go undetected.

For all of these reasons, LILCO has determined that real time monitors are unnecessary for the Shoreham plant.

Q25. Please summarize your testimony.

A25. [Blauer, Cordaro, Schmitt] In summary, LILCO does not intend to use real time monitors at fixed locations that can be remotely interrogated. The real time monitoring system limitations include:

1. no indication of an impending release,
2. little warning time to initiate protective actions,
3. uncertainty that the plumes may rise above or pass to the side of a monitoring location and thus miss the fixed monitor completely,
4. inability to measure radioiodine air concentrations,
5. uncertainty in determining plume center line and plume boundaries,
6. low sensitivity to determine the magnitude of an unmonitored release in the presence of a monitored release, and
7. uncertainty projecting downwind dose rates.

The equipment LILCO intends to use to monitor releases provides information regarding radioiodine, particulate and noble gas releases to the environment. Downwind survey teams can scan for the plume centerline and the plume boundary and determine atmospheric radioiodine concentrations. The REMP can collect specific media in each portion of the aquatic, terrestrial and atmospheric environment including direct accumulated radiation dosimetry using TLD's. Together, these systems, equipment and methods provide timely, accurate and detailed information for predicting and calculating dose assessment. Thus, LILCO has the ability to assess

accidents and monitor radiolcgical releases from the Shoreham facility in the event of a radiological emergency.

PROFESSIONAL QUALIFICATIONS

H. MARK BLAUER

Chairman, Emergency Planning Task Force

Emergency Planning Coordinator

LONG ISLAND LIGHTING COMPANY

My name is H. Mark Blauer. My business address is Long Island Lighting Company, 175 East Old Country Road, Hicksville, New York 11801. I am Chairman of the Emergency Planning Task Force and Emergency Planning Coordinator. In this capacity, I report to the Vice Presdient, Nuclear, and the Vice President, Engineering. I also report to the Manager, Nuclear Engineering Department. My duties include overall technical and administration responsibility for the Emergency Planning Task Force. The Task Force is responsible for developing and maintaining the Shoreham Nuclear Power Station Emergency Plan; Emergency Training curriculum, manuals, and lesson plans; qualification and selection of emergency response personnel; Emergency Plan procedures; onsite and offsite emergency support facilities; the Prompt Notification System; the interfacing with Federal (NRC, DOE, FEMA, Coast Guard), State (Department of Health, Disaster Preparedness Commission) and Local (Suffolk County,

hospitals and fire departments) authorities as well as other nuclear industry support groups (INPG).

I received my Bachelor and Master of Science degrees from the State University of New York at Stony Brook in 1968 and 1971, respectively. I received my Doctorate in Nuclear Chemistry from the University of Glasgow, Scotland in 1977.

From 1971 to 1975 I was a Research Assistant (U.S. equivalent: Assistant Professor) at the University of Glasgow teaching nuclear chemistry and researching low-level tritium techniques. I was a Research Assistant (U.S. equivalent: Assistant Professor) at University College, London from 1975 to 1977 teaching isotope geology, researching major and trace element techniques and acting as consultant to several water authorities. During this period the following were published:

Anderson, A., Blauer, H. M. and Baxter, M.S. (1977). A controlled power supply for the electrolytic enrichment of tritium, J. Physics, V10, pp. 1286-1294.

Beckinsale, R.D., Bowles, J.F.W., Pankhurst, R.J., Wells, M.K. and Blauer, H.M. (1977). Rubidium-strontium age studies and geochemistry of acid veins in the Freetown complex, Sierra Leone, Mineralogical Magazine, V41, pp. 501-511.

Blauer, H.M., Baxter, M.S. and Anderson, A. (1978). An improved technique for the electrolytic enrichment of tritium, Analyst, V103, pp. 823-829.

Hope, C.A., Blauer, H.M. and Reiderer, J. (1980). Recent analysis of 18th dynasty pottery in "Studien zur Altagyptischen Keramic," edited Dorothea Arnold, Philip von Zabern, Mainz.

In 1977 I returned to the United States and assumed the

position of Assistant Professor at the University of Pittsburgh, Department of Radiation Health from 1977 to 1980. I taught radiation health, radiation chemistry and nuclear chemical separation techniques; researched bioassay techniques and low-level environmental measurement techniques; directed an EPA certified radio-chemical laboratory; and consulted with several major uranium producers. During this period the following were published:

Dennis, Nancy A., Blauer, H. Mark, and Kent, Jacqueline E. (1981). Dissolution fractions and half-times of single source yellowcake in simulated lung fluids, Health Physics, V41.

Culp, P. and Blauer, H.M. (1979). Dissolution rates of radionucleides from coal and coal ashes, Twenty-fourth Annual Meeting of the Health Physics Society, Philadelphia, PA.

Dennis, N.A. and Blauer, H.M. (1979). Dissolution rates of uranium in yellowcake in simulated lung fluids, Twenty-fourth Annual Meeting of the Health Physics Society, Philadelphia, PA.

Padezanin, T. and Blauer, H.M. (1979). Comparison of uranium urinalysis methods, Twenty-fourth Annual Meeting of the Health Physics Society, Philadelphia, PA.

Blauer, H.M. and Dennis, N.A. (1979). Dissolution rates of uranium from single source yellowcake in both simulated interstitial and surfactant lung fluids, Twenty-fifth Annual Conference on Bioassay, Enviromental and Analystical Chemistry, Las Vegas, N.Y.

Maitz, A.H. and Blauer, H.M. (1980). Pure uranium oxides: their dissolution rates plus relationship to yellowcake dissolution characteristics, Twenty-fifth Annual Meeting of the Health Physics Society, Seattle, WA.

Blauer, H.M. and Brown, S.H. (1980). Physical and chemical parameters affecting dissolution

characteristics of yellowcake in simulated lung fluids, Twenty-fifth Annual Meeting of the Health Physics Society, Seattle, WA.

Brown, S.H. and Blauer, H.M. (1980). Characterization of yellow-cake (U308) from multiple sources and some implications regarding uranium mill bioassay, Twenty-fifth Annual Meeting of the Health Physics Society, Seattle, WA.

From 1980 to 1981 I was Environmental Scientist at Three Mile Island Nuclear Generating Station responsible for audits, the Radiological Environmental Monitoring Program, offsite dose calculations and health effects studies. During this period the following positions and procedures were written:

Blauer, H. Mark (1981). Three Mile Island Nuclear Station, Comments on the Articles "The First Casualty at TMI" and "The Lethal Path of TMI Fallout" by Ernest J. Sternglass.

Blauer, H. Mark (1981) TMI Enviromental Controls REMP Procedure, Determination of REMP investigation levels and subsequent actions, ECP 1507, Rev. 1.

Blauer, H. Mark (1981) TMI Environmental Controls Emergency REMP Procedure, operating procedure for the CRT, ECP 1601, Rev. 0.

Blauer, H. Mark (1981) TMI Environmental Controls Emergency REMP Procedure Determination of Off-Site Dose, ECP 1602, Rev. 1.

Blauer, H. Mark (1981) TMI Environmental Controls Procedure Ge(li) detector system using series 80, ECP 1719, Rev. 0.

I joined LILCO in 1981 as Senior Scientist, Nuclear Licensing Division. My responsibilities include providing support to corporate and plant staff in the areas of Radiation

Protection, Health Physics, ALARA, Emergency Planning and REMP. In 1982 I became Chairman of the Emergency Planning Task Force responsible for all technical and administrative functions. During this period, the following courses and procedures were prepared:

General Physics - BWR Familiarization Course (1 week)

LILCO - BWR Familiarization Course (2 weeks)

Blauer, H. Mark (1981) REMP data receipt and running tables, RP 4.2, Rev. 0

Blauer, H. Mark (1981) Anomalous data results - LLD and positive value exceptions, RP 4.3, Rev. 0

Blauer, H. Mark (1982) Acceptance Criteria, RP 4.4, Rev. 0

Blauer, H. Mark (1982) Determination of REMP investigation levels and subsequent actions, RP 4.5, Rev. 0.

I am certified by the American Chemical Society and a member of the American Geophysical Union and Health Physics Society.

PROFESSIONAL QUALIFICATIONS

MATTHEW C. CORDARO

Vice President of Engineering

LONG ISLAND LIGHTING COMPANY

My name is Matthew C. Cordaro. My business address is Long Island Lighting Company, 175 East Old Country Road, Hicksville, New York 11801. I am currently Vice President of Engineering and have held this position since the spring of 1978. As Vice President of Engineering, I am responsible for all of LILCO's engineering activities. This includes responsibility in the areas of facility planning and engineering for nuclear and fossil electric generating plants, as well as electric and gas transmission and distribution systems. In addition, I am responsible for assessing the environmental impacts of all LILCO operations.

I received my Bachelor of Science degree in Engineering Science from C. W. Post College in 1965. I received my Master of Science degree in Nuclear Engineering from New York University in 1967. I received my Doctorate in Applied Nuclear Physics from the Cooper Union School of Engineering and Science in 1970. I was awarded the Atomic Energy Commission Special Fellowship in Nuclear Science and Engineering

My past professional affiliations include a position as Guest Research Associate at Brookhaven National Laboratory, Adjunct Associate Professor of Nuclear Engineering at Polytechnic Institute of New York and Adjunct Assistant Professor at C. W. Post College.

I joined LILCO in 1966 and from 1966 to 1970 I held the positions of Assistant Engineer (1966), Associate Engineer (1967), Nuclear Physicist (1968) and Senior Environmental Engineer (1970). In these earliest positions with LILCO I was involved as a principal in all phases of nuclear power plant design, licensing and fuel management. I was also a lead witness for the Company in Federal and State licensing proceedings for the Shoreham and Jamesport Nuclear Power Stations.

In 1972 I assumed the position of Manager of Environmental Engineering. In this capacity I was responsible for the environmental impact of all LILCO operations. This position involved the supervision, administration and direction of all environmental programs aimed at demonstrating compliance with applicable standards.

I am a member of a number of related professional organizations including: the Board of Directors, Adelphi University's Center on Energy Studies; and the Council of Overseers, C. W. Post College. Other related professional

affiliations are: the Technical Resources Advisory Council to the New York State Department of Environmental Conservation; the New York Power Pool Environmental Committee; Advisory Task Forces and Committees of the Atomic Industrial Forum; the Long Island Association of Commerce and Industry Environmental Committee; the Advisory Board to Environmental Technology Seminar; the Environment and Energy Committee of the Edison Electric Institute; and the HSA Environmental Task Force. I have also been a member of the Research Planning Advisory Committee for the New England River Basins Commission Study of Long Island Sound, the Marine Advisory Council to the New York State Sea Grants Seminar, and the Nassau-Suffolk Health Systems Agency (HSA), Suffolk County Council.

In addition, I am a member of the American Nuclear Society, the Health Physics Society and the Environmental Technology Seminar.

My most recent publications include a paper on methodology for power plant site selection, papers presented at the World Energy Conference on space heating alternatives and power plant cooling systems, a paper related to power plant waste heat utilization, and a paper on the transportation of nuclear wastes. I have also published journal articles in the fields of environmental science and nuclear science, as well as

numerous studies and reports related to the environmental effects of energy production.

I recently testified before Congressional Committees on Nuclear Waste Transport and the Economics and Environmental Impacts of Coal Utilization.

PROFESSIONAL QUALIFICATIONS

JOHN F. SCHMITT

Radiochemistry Engineer

LONG ISLAND LIGHTING COMPANY

My name is John F. Schmitt. I am the Radiochemistry Engineer of the Shoreham Nuclear Power Station, a position I have held since January 1975. As such, I am responsible for developing and implementing the chemistry, radiochemistry and effluent monitoring program for Shoreham. This includes, among other things, directing all work related to conducting the chemical and radiochemical analyses and treatments of plant process systems; detecting and controlling environmental releases; implementing the ALARA policy for these releases; and preparing records and reports of chemical surveys.

I graduated from Manhattan College in 1966 with a Bachelor of Science degree in chemistry and received a Master of Science degree in Environmental Health Science, specializing in Radiological Health (Health Physics), from the University of Michigan in 1974 and became a Certified Health Physicist in 1982. I completed the General Electric Boiling Water Reactor Chemistry Course in November 1975. I have also completed many industry seminars and training programs, including:

a. Radiation Protection - LILCO Evening Institute

b. Radiation Protection Workshops - General Electric Company

c. BWR Chemistry Training - General Electric Company

d. Health Physics Review - Rockwell International

e. Accelerated Health Physics Instruction - NUS

f. Accelerated Nuclear Plant Chemistry Instruction - NUS

g. Health Physics Review - Brookhaven National Labs

h. Environmental Radiation Surveillance - Harvard School of Public Health

i. Radioactive Waste Management for Nuclear Power Reactors - ASME/University of Virginia

j. Post Accident Sampling Workshops - Sentry Equipment, EPRI

k. Control of Plant Radiation Fields - EPRI, General Electric Company

l. Atomic Absorption/Atomic Emission Spectrometry - Instrumentation Labs

m. Gamma Spectrometer Operation - Canberra Industries

I started work for the Long Island Lighting Company in 1966 as an Assistant Engineer at the Far Rockaway Power Station. I took a military leave of absence from 1967-1972 to serve as an officer in the U.S. Air Force. Returning to LILCO in 1972, I was an Associate Engineer at the Glenwood Power Station. From 1973 until assuming my present position in 1975, I was assigned to the staff of the Shoreham Nuclear Power Station as an Associate Engineer and Plant Engineer. During this time, I studied health physics at the University of

Michigan and received training at the AEC's Savannah River Plant and Commonwealth Edison's Dresden Nuclear Power Station.

I am a member of the Health Physics Society, New York Chapter of the Health Physics Society, Power Reactor Health Physicists, and the Long Island Chapter of the American Nuclear Society.

Attachment 10(B)

SECY 82-111

NRC STAFF RECOMMENDATIONS

ON THE

REQUIREMENTS FOR

EMERGENCY RESPONSE CAPABILITY

March 10, 1982

CONTENTS

CONTENTS (Continued)

EMERGENCY RESPONSE CAPABILITY

1. INTRODUCTION

This report was prepared as a result of a review by the Committee to Review Generic Requirements (CRGR). The recommendations herein have been developed by the program offices and are supported by CRGR. The report represents the staff's attempt to distill the fundamental requirements for nuclear plant Emergency Response Capability from the wide range of guidance documents that NRC has issued. It is not intended that these guidance documents (NUREG reports and Regulatory Guides) be ignored; they are still useful sources of guidance for licensees and NRC staff regarding acceptable means for meeting the fundamental requirements contained in this document.

These fundamental requirements are further specification of the general guidance specified previously by the Commission in its regulations, orders and policy statements on emergency planning and TMI issues. It is intended that these fundamental requirements would be applicable to licensees of operating nuclear power plants and holders of construction permits for nuclear power plants. For applicants for a construction permit (CP) or manufacturing license (ML), the requirements described in this document must be supplemented with the specific provisions in the rule specifying licensing requirements for pending CP and ML applications. In this regard, it is expected that the staff would review CP and ML applications against the guidance in the current Standard Review Plan, and this might lead to more detailed requirements than prescribed in this document.

Based on discussions with licensees, the staff has learned that many of the Commission approved schedules for emergency response facilities probably will not be met. In recognition of this fact and the difficulty of implementing generic deadlines, the staff proposes that plant-specific schedules be established which take into account the unique status of each plant. The following sequence for developing implementation schedules is proposed.

When the basic requirements for emergency response capabilities and facilities are finalized, they should be transmitted to licensees by a generic letter from NRR, promulgated to NRC staff, and incorporated as regulatory requirements (e.g., in the Standard Review Plan or by regulation or Order, as appropriate). The letter to licensees should request that licensees submit a proposed schedule for completing actions to comply with the basic requirements. Each licensee's proposed schedules would then be reviewed by the assigned NRC Project Manager, who would discuss the subject with the licensee and mutually agree on schedules and completion dates. The implementation dates would then be formalized into an enforceable document.

The basic requirements in this document do not alter previously issued guidance, which remains in effect. This document does attempt to place that guidance in perspective by identifying the elements that the NRC staff believes to be essential to upgraded emergency response capabilities. The proposal to formalize implementation dates in an enforceable document reflects the level of importance which the NRC staff attributes to these basic requirements. The NRC staff does not recommend that existing guidance be imposed in this manner, but rather that it be used as guidance to be considered in upgrading emergency response capabilities. This indicates the distinction which the staff believes should be made between the basic requirements and guidance.

The following sections describe NRC staff recommendations on basic requirements, their interrelationships, and NRC actions to improve management of emergency response regulation. Reference documents are cited with a description of content as it relates to specific initiatives.

2. USE OF EXISTING DOCUMENTATION

The NRC staff recommends that the following NUREG documents are intended to be used as sources of guidance and information, and the Regulatory Guides are to be considered as guidance or as an acceptable approach to meeting formal requirements. The items by virtue of their inclusion in these documents shall not be misconstrued as requirements to be levied on licensees or as inflexible criteria to be used by NRC staff reviewers.

NUREG Report		Titles
0696	-	Functional Criteria for Emergency Response Facilities
0700	-	Guidelines for Control Room Design Reviews
0799	-	Draft Criteria for Preparation of Emergency Operating Procedures
0801	-	Evaluation Criteria for Control Room Design Reviews
0814	-	Methodology for Evaluation of Emergency Response Facilities
0818	-	Emergency Action Levels for Light Water Reactors
0835	-	Human Factors Acceptance Criteria for SPDS

Regulatory Guides		
1.23 (Rev. 1)	-	Meteorological Measurement Program for Nuclear Power Plants
1.97 (Rev. 2)	-	Instrumentation for Light-Water Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident
1.101 (Rev. 2)	-	Emergency Planning for Nuclear Power Plants
1.47	-	Bypassed and Inoperable Status Indication for Nuclear Power Plant Safety Systems

3. COORDINATION AND INTEGRATION OF INITIATIVES

1. The design of the Safety Parameter Display System (SPDS), design of instrument displays based on Regulatory Guide 1.97 guidance, control room design review, development of symptom oriented emergency operating procedures, and operating staff training should be integrated with respect to the overall enhancement of operator ability to comprehend plant conditions and cope with emergencies. Assessment of information needs and display formats and locations should be performed by individual licensees. The SPDS could affect other control room improvements that licensees may consider. In some cases, a good SPDS may obviate the need for large-scale control room modifications. However, installation of the SPDS should not be delayed by slower progress on other initiatives. The SPDS should not be contingent on completion of the control room design review. NRC does not plan to impose additional requirements on licensees regarding SPDS.

2. Implementation of part or all of Regulatory Guide 1.97 (Rev. 2) represents a control room improvement. The implementation of control room improvements is not contingent on implementing Technical Support Center (TSC) and Emergency Operations Facility (EOF) requirements.

3. The Technical Support Center (TSC) and Emergency Operations Facility (EOF) are dependent on control room improvements in terms of communication and instrumentation needs among the TSC, EOF, and control room. TSC and EOF facilities are not necessarily dependent on each other. The Operational Support Center (OSC) is independent of TSC and EOF.

4. The three groups of initiatives--SPDS, control room improvements, and emergency response facilities (TSC, EOF, OSC)--should have the following interrelationships:

    a. The SPDS is an improvement in the control room because it enhances operator ability to comprehend plant conditions and interact in situations that require human intervention. The SPDS could affect other control room improvements that licensees may consider. In some cases, a good SPDS could obviate the need for extensive modifications to control rooms.

    b. New instrumentation that may be added to the control room should be considered a requirement for inclusion in the design of the TSC and EOF only to the extent that such instrumentation is essential to the performance of TSC and EOF functions.

    c. The SPDS and control room improvements are essential elements in operator training programs and the upgraded plant-specific emergency operating procedures.

    d. Acquisition, processing, and management of data for SPDS, control room improvements, and emergency response facilities should be coordinated but need not be centralized.

5. Specific implementation plans and reasonable, achievable schedules should be established by agreement between the NRC Project Manager and each individual licensee. The NRC office responsible for implementing each requirement should develop procedures identifying the following:

   a. The respective roles of NRR, IE, and Regional Offices in managing implementation, checking licensee rate of progress, and verifying compliance, including the extent to which NRC review and inspection is necessary during implementation.

   b. Procedural methods and enforcement measures that could be used to ensure NRC staff and licensee attention to meeting mutually agreed upon schedules without significant delays and extensions.

6. The NRC Project Manager for each nuclear power plant is assigned program management responsibility for NRC staff actions associated with implementing emergency response initiatives. The NRC Project Manager is the principal contact for the licensee regarding these initiatives.

7. NRC will make allowances for work already done by licensees in a good-faith effort to meet requirements as they understand them. For each case in which a licensee would have to remove or rip out emergency response facilities or equipment that was installed in good faith to meet previous guidance in order to meet the basic requirements described in this document, the Director of the Office of Nuclear Reactor Regulation or Inspection and Enforcement will review the circumstances and determine whether removal is necessary or existing facilities or equipment represent an acceptable alternative. Any regulatory position that would require the removal or major modification of existing emergency response facilities or equipment requires the specific approval of the Office Director.

8. NRC recognizes that acceptable alternative methods of phasing and integrating emergency response activities may be developed. Each licensee needs flexibility in integrating these activities, taking into account the varying degree to which the licensee has implemented past requirements and guidance. An example of a way in which these activities could be integrated is discussed below. Other methods of integration proposed by licensees would be reviewed considering licensees' progress on each initiative.

   a. SPDS

      (1) Review the functions of the nuclear power plant operating staff that are necessary to recognize and cope with rare events that (a) pose significant contributions to risk, (b) could cause operators to make cognitive errors in diagnosing them, and (c) are not included in routine operator training programs.

      (2) Combine the results of this review with accepted human factors principles to select parameters, data display, and functions to be incorporated in the SPDS.

(3) Design, build, and install the SPDS in the control room and train its users.

b. To be done parallel without delaying SPDS, complete emergency operating procedure technical guidelines that will be used to develop plant-specific emergency operating procedures.

c. Using these EOP technical guidelines, the SPDS design, and accepted human factors principles, conduct a review of the control room design. Apply the results of this review to:

(1) Verify SPDS parameter selection, data display, and functions.
(2) Develop plant-specific EOPs.
(3) Design control room modifications that correct conditions adverse to safety (reduce significant contributions to risk), and add additional instrumentation that may be necessary to implement Regulatory Guide 1.97.
(4) Train and qualify plant operating staff regarding EOPs and modifications.

d. Verify, prior to finalization of designs for modifications and of procedures and training, that the functions of control room operators in emergencies can be accomplished (i.e., that the individual initiatives have been integrated sufficiently to meet the needs of control room operators and provide adequate emergency response capabilities).

e. Implement EOPs and install control room modifications coincident with scheduled outages as necessary, and train operators in advance of these changes as they are phased into operation.

4. SAFETY PARAMETER DISPLAY SYSTEM (SPDS)

Current Regulatory Requirements

No licensee action is required.

Functional Statement

The SPDS should provide a concise display of critical plant variables to the control room operators to aid them in rapidly and reliably determining the safety status of the plant. Although the SPDS will be operated during normal operations as well as during abnormal conditions, the principal purpose and function of the SPDS is to aid the control room personnel during abnormal and emergency conditions in determining the safety status of the plant and in assessing whether abnormal conditions warrant corrective action by operators to avoid a degraded core. This can be particularly important during anticipated transients and the initial phase of an accident.

Recommended Requirements

1. Each operating reactor shall be provided with a Safety Parameter Display System that is located convenient to the control room operators. This system will continuously display information from which the plant safety status can be readily and reliably assessed by control room personnel who are responsible for the avoidance of degraded and damaged core events.

2. The control room instrumentation required (see General Design Criteria 13 and 19 of Appendix A to 10 CFR 50) forms the basic safety components required for safe reactor operation under normal, transient, and accident conditions. The SPDS is used in addition to the basic components and serves to aid and augment these components. Thus, requirements applicable to control room instrumentation are not needed for this augmentation (e.g., GDC 2, 3, 4 in Appendix A; 10 CFR Part 100; single-failure requirements). The SPDS need not meet requirements of the single-failure criteria and it need not be qualified to meet Class 1E requirements. The SPDS shall be suitably isolated from electrical or electronic interference with equipment and sensors that are in use for safety systems. The SPDS need not be seismically qualified, and additional seismically qualified indication is not required for the sole purpose of being a backup for SPDS. After the SPDS has been installed, operating procedures should be available that will allow timely and correct safety status assessment when the SPDS is not available.

3. There is a wide range of useful information that can be provided by various systems. This information is reflected in such staff documents as NUREG-0696, NUREG-0835, and Regulatory Guide 1.97.

   Prompt implementation of an SPDS can provide an important contribution to plant safety. The selection of specific information that should be provided for a particular plant shall be based on engineering judgment of individual plant licensees, taking into account the importance of prompt implementation.

4. The SPDS display shall be designed to incorporate accepted human factors principles so that the displayed information can be readily perceived and comprehended by SPDS users.

5. Minimum information to be provided shall be sufficient to provide information to plant operators about:

   a. Reactivity control
   b. Reactor core cooling and heat removal from the primary system
   c. Reactor coolant system integrity
   d. Radioactivity control
   e. Containment conditions

   The specific parameters to be displayed shall be determined by the licensee.

6. The licensee shall prepare a written safety analysis describing the basis on which the selected parameters are sufficient to assess the safety status of each identified function for a wide range of events, which include symptoms of severe accidents. Such analysis, along with the specific implementation plan for SPDS shall be reviewed as described below.

7. The licensee's proposed implementation of an SPDS system shall be reviewed in accordance with the licensee's technical specifications to determine whether the changes involve an unreviewed safety question or change of technical specifications. If they do, they shall be processed in the normal fashion with prior NRC review. If the changes do not involve an unreviewed safety question or a change in the technical specifications, the licensee may implement such changes without prior approval by NRC. However, the licensee's analysis shall be submitted to NRC promptly on completion of review by the licensee's offsite committee. Based on the results of NRC review, the Director of IE or the Director of NRR may request or direct the licensee to cease implementation if a serious safety question is posed by the licensee's proposed system, or if the licensee's analysis is seriously inadequate.

Integration

Prompt implementation of an SPDS is a design goal and of primary importance. The schedule for implementing SPDS should not be impacted by schedules for the control room design review and development of symptom-oriented emergency operating procedures. For this reason, licensees should develop and propose an integrated schedule for implementation in which the SPDS design is an input to the other initiatives. If reasonable, this schedule should be accepted by NRC.

Reference Documents

NUREG-0660 -- Need for SPDS identified

March 11, 1982

SECY-82-111

POLICY ISSUE
(Notation Vote)

For: The Commissioners

From: William J. Dircks
Executive Director for Operations

Subject: REQUIREMENTS FOR EMERGENCY RESPONSE CAPABILITY

Purpose: To request Commission approval of a set of basic requirements for emergency response capability and approval for the staff to work with licensees to develop plant-specific implementation schedules.

Discussion: One of the first issues reviewed by the Committee to Review Generic Requirements (CRGR) was the broad area of emergency response facilities and capabilities at nuclear plants. The Committee found that implementation schedules were not being coordinated within the NRC. In addition, existing NRC documents published as guidance to licensees were sometimes being used as firm requirements. Discussions with industry representatives and the staff indicated that some licensees had slowed down on work in this area pending NRC clarification of its requirements. Some utilities have virtually stopped work on some of the items, while others have proceeded and, in some cases, completed some of the items. The Committee recommended that steps be taken by the Office Directors involved to clarify the requirements and implementation schedules for the Safety Parameter Display System (SPDS), Control Room Design Review, upgraded Emergency Operating Procedures, Regulatory Guide 1.97, Technical Support Center (TSC), Operational Support Center (OSC), and Emergency Operations Facility (EOF). In my memo to the Commission dated December 31, 1981, I noted that the DEDROGR staff would work with the program offices to clarify the basic requirements in this area and establish a revised implementation plan.

Enclosed are the staff's recommendations for the requirements in the broad area of emergency response facilities and capabilities outlined above. The requirements were developed by the program offices

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V. Stello, Jr., DEDROGR
49-29704

and are supported by CRGR. The enclosure represents a distillation of fundamental requirements from the broad range of guidance documents that NRC has issued (principally NUREG reports and Regulatory Guides). The staff intends that the guidance documents referred to in the enclosure not be used to impose requirements on licensees, but rather that they be used as sources of guidance for NRC reviewers and licensees regarding acceptable means for meeting the fundamental requirements proposed.

In discussions with owners' groups and individual licensees, the staff has learned that the Commission approved schedule of October 1, 1982, for implementation of the TSC and EOF probably cannot be met. In recognition of this fact and the difficulty of implementing generic deadlines, the staff is proposing that plant-specific schedules be established which take into account the unique status of each plant. Each licensee would be requested to submit a proposed schedule for completing the actions to comply with the fundamental requirements. The NRC Project Manager for each plant should be knowledgeable of the overall work effort going on at a plant and, based on guidance received from NRC management, could reach agreement with licensees on schedules which optimize use of utility and NRC resources. The agreed upon completion dates would be formalized in an order. By this approach, future staff coordination problems regarding implementation schedules will be avoided.

Resource Estimates: The costs to licensees to implement the requirements proposed in the enclosure were included in the estimates set out in NUREG-0660.

Recommendation: That the Commission:

1. Approve the fundamental requirements described in the enclosure.

2. Approve the issuance of the requirements in the enclosure by 50.54f letters as a revision to NUREG 0737.

3. Approve the method for establishing plant-specific implementation schedules described in the enclosure.

4. Approve the implementation of these requirements through plant-specific orders.

5. Note that the staff intends to use the previously issued NUREG reports and Regulatory Guides as guidance documents only.

Scheduling: Licensees are currently required to establish a TSC and EOF by October 1. Prompt action on this paper is required in order to provide guidance to licensees.

William J. Dircks
Executive Director for Operations

Enclosure:
NRC Staff Recommendation on the Requirements for Emergency Response Capability

Commissioners' comments should be provided directly to the Office of the Secretary by c.o.b. Monday, March 29, 1982.

Commission Staff Office comments, if any, should be submitted to the Commissioners NLT Monday, March 22, 1982, with an information copy to the Office of the Secretary. If the paper is of such a nature that it requires additional time for analytical review and comment, the Commissioners and the Secretariat should be apprised of when comments may be expected.

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ENCLOSURE

EMERGENCY RESPONSE CAPABILITY

COMMISSION BRIEFING

VICTOR STELLO, JR.

APRIL 15, 1982

COMMISSION DECISIONS RECOMMENDED

1. APPROVAL OF STAFF'S PROPOSED SET OF BASIC REQUIREMENTS WHICH HAVE BEEN DISTILLED FROM THE BROAD RANGE OF GUIDANCE DOCUMENTS THAT NRC HAS ISSUED.

2. APPROVAL OF STAFF'S PROPOSED IMPLEMENTATION PLAN

   -- ISSUE PROPOSED REQUIREMENTS TO LICENSEES BY 50.54f LETTERS AS A REVISION TO NUREG-0737

   -- ESTABLISH PLANT-SPECIFIC SCHEDULES BY MUTUAL AGREEMENT WITH LICENSEES

   -- FORMALLY IMPLEMENT REQUIREMENTS AND SCHEDULES THROUGH PLANT-SPECIFIC ORDERS

BACKGROUND

CRGR REVIEW OF OVERALL NRC ACTIVITIES IN EMERGENCY RESPONSE (12/3/81)

-- NRC OFFICE ACTIVITIES NEEDED BETTER COORDINATION

-- ACTUAL REQUIREMENTS NOT CLEAR

-- NUREGS AND REG GUIDES SOMETIMES USED BY STAFF AS FIRM REQUIREMENTS

INITIAL DRAFT OF STAFF RECOMMENDATIONS (12/29/81)

ACRS BRIEFING (1/8/82)

FINAL STAFF RECOMMENDATIONS CONSIDERING ALL COMMENTS (3/10/82)

SCOPE

EMERGENCY RESPONSE FACILITIES

-- TECHNICAL SUPPORT CENTER (TSC)

-- OPERATIONAL SUPPORT CENTER (OSC)

-- EMERGENCY OPERATIONS FACILITY (EOF)

CONTROL ROOM IMPROVEMENTS

-- SAFETY PARAMETER DISPLAY SYSTEM (SPDS)

-- CONTROL ROOM DESIGN REVIEW

-- INSTRUMENTS FOR ACCIDENTS (AS IDENTIFIED IN REG GUIDE 1.97)

OPERATOR CAPABILITY

-- IMPROVED EMERGENCY OPERATING PROCEDURES

-- TRAINING

PROPOSED BASIC REQUIREMENTS - INTEGRATION OF ACTIVITIES

IT IS ESSENTIAL THAT THE ACTIVITIES ON CONTROL ROOM IMPROVEMENTS, UPGRADING OF EMERGENCY OPERATING PROCEDURES, AND STAFF TRAINING BE INTEGRATED AT EACH PLANT. THE TSC AND EOF DESIGN AND IMPLEMENTATION ARE RELATED TO CONTROL ROOM IMPROVEMENTS IN COMMUNICATIONS AND INSTRUMENTATION.

PROPOSED BASIC REQUIREMENTS - SPDS

-- PROMPT IMPLEMENTATION OF SPDS IS IMPORTANT AS A SAFETY IMPROVEMENT, PROVIDING INFORMATION, AS A MINIMUM, ON:

* REACTIVITY CONTROL
* REACTOR CORE COOLING AND HEAT REMOVAL
* REACTOR COOLANT SYSTEM INTEGRITY
* RADIOACTIVITY CONTROL
* CONTAINMENT CONDITIONS

-- SHOULD BE DESIGNED ACCORDING TO GOOD HUMAN FACTORS PRINCIPLES

-- MUST BE CONSIDERED DURING CONTROL ROOM DESIGN REVIEW

-- NO SEISMIC, CLASS 1E OR SINGLE-FAILURE REQUIREMENTS

-- POST-IMPLEMENTATION REVIEW

PROPOSED BASIC REQUIREMENTS - CONTROL ROOM DESIGN REVIEW

-- PURPOSE IS TO IDENTIFY HUMAN ENGINEERING DISCREPANCIES

-- MULTIDISCIPLINARY REVIEW TEAM

-- FUNCTION AND TASK ANALYSIS REQUIRED

-- SIGNIFICANT DISCREPANCIES SHOULD BE CORRECTED

-- MUST BE INTEGRATED WITH OTHER ACTIVITIES SUCH AS SPDS, UPGRADED EMERGENCY OPERATING PROCEDURES, OPERATOR TRAINING AND NEW REG GUIDE INSTRUMENTATION

-- NRR REVIEW ON AN AUDIT BASIS

PROPOSED BASIC REQUIREMENTS - REG GUIDE 1.97

FOR CONTROL ROOM - INDICATION OF TYPE A,B,C,D,E VARIABLES
- INDICATION OF WIND DIRECTION, SPEED AND ATMOSPHERIC STABILITY
- EQUIPMENT QUALIFICATION AS DETERMINED BY PENDING RULEMAKING

FOR TSC
- INDICATION OF TYPE A,B,C,D,E VARIABLES NEEDED FOR TSC FUNCTION
- NEED NOT MEET CLASS 1E, SINGLE-FAILURE OR SEISMIC QUALIFICATION REQUIREMENTS

FOR EOF
- INDICATION OF VARIABLES NECESSARY TO PERFORM EOF FUNCTION
- NEED NOT MEET CLASS 1E, SINGLE-FAILURE OR SEISMIC QUALIFICATION REQUIREMENTS

PROPOSED BASIC REQUIREMENTS - EMERGENCY OPERATING PROCEDURES

-- REANALYZE ACCIDENTS AND PREPARE TECHNICAL GUIDELINES

-- UPGRADE EMERGENCY OPERATING PROCEDURES CONSISTENT WITH GUIDELINES

-- OPERATOR TRAINING ON PROCEDURES PRIOR TO IMPLEMENTATION

-- MUST BE INTEGRATED WITH SPDS AND CONTROL ROOM DESIGN REVIEW

-- NRC REVIEW AND APPROVAL OF TECHNICAL GUIDELINES

-- OPPORTUNITY FOR PREIMPLEMENTATION REVIEW OF PROCEDURES

PROPOSED BASIC REQUIREMENTS - EMERGENCY RESPONSE FACILITIES

-- GENERAL REQUIREMENTS SPECIFIED FOR: LOCATION
   SIZE
   RADIATION PROTECTION
   RECORDS
   EQUIPMENT
   COMMUNICATIONS
   STAFFING

-- NO NRC APPROVAL OF CONCEPTUAL DESIGNS REQUIRED BEFORE CONSTRUCTION

PROPOSED IMPLEMENTATION PLAN

-- ISSUE PROPOSED BASIC REQUIREMENTS TO LICENSEES BY 50.54f LETTERS AS A REVISION TO NUREG 0737

-- NRC PROJECT MANAGERS (WITH MANAGEMENT GUIDANCE) NEGOTIATE PLANT-SPECIFIC SCHEDULES WITH LICENSEES

-- NRR IMPLEMENT FORMAL REQUIREMENTS THROUGH PLANT-SPECIFIC ORDERS

-- CURRENT OCTOBER 1982 GENERIC DEADLINE FOR OPERATIONAL EMERGENCY RESPONSE FACILITIES WILL BE EXTENDED ON CASE-BY-CASE BASIS

-- DESIGN AND INSTALLATION OF INPLANT SYSTEMS AND FACILITIES SHOULD BE EXPEDITED

STAFF USE OF NUREGS AND REG GUIDES

-- TO BE USED AS GUIDANCE ONLY, NOT REQUIREMENTS

-- EDO INSTRUCTIONS TO STAFF

-- DISCLAIMER STATEMENT IN NUREGS

NUREG-0737	--	Specified SPDS
NUREG-0696	--	Functional criteria for SPDS
NUREG-0835	--	Specific acceptance criteria keyed to 0696
Reg. Guide 1.97 (Rev. 2)	--	Instrumentation for Light-Water Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident

5. DETAILED CONTROL ROOM DESIGN REVIEW

Current Regulatory Requirements

As specified in Item I.D.1 in NUREG-0737, the implementation schedule is still to be developed.

Functional Statement

The objective of the control room design review is to "improve the ability of nuclear power plant control room operators to prevent accidents or cope with accidents if they occur by improving the information provided to them" (from NUREG-0660, Item I.D.1). As a complement to improvements of plant operating staff capabilities in response to transients and other abnormal conditions that will result from implementation of the SPDS and from upgraded emergency operating procedures, this design review will identify any modifications of control room configurations that would contribute to a significant reduction of risk and enhancement in the safety of operation. Decisions to modify the control room would include consideration of long-term risk reduction and any potential temporary decline in safety after modifications resulting from the need to relearn maintenance and operating procedures. This should be carefully reviewed by persons competent in human factors engineering and risk analysis.

Recommended Requirements

1. Conduct a control room design review to identify human engineering discrepancies. The review shall consist of:

   a. The establishment of a qualified multidisciplinary review team and a review program incorporating accepted human engineering principles.

   b. The use of function and task analysis (that had been used as the basis for developing emergency operating procedure Technical Guidelines) to identify control room operator tasks and information and control requirements during emergency operations. This analysis has multiple purposes and should also serve as the basis for developing training and staffing needs and verifying SPDS parameters.

   c. A comparison of the display and control requirements with a control room inventory to identify missing and surplus (distracting) displays and controls.

   d. A control room survey to identify deviations from accepted human factors principles. This survey will include, among other things, assessment of control room layout, the usefulness of audible and visual alarm systems, information recording and recall capability, and control room environment.

2. Assess which human engineering discrepancies are significant and should be corrected. Select design improvements that will correct those discrepancies. Improvements that can be accomplished with an enhancement program (paint-tape-label) should be done promptly.

3. Verify that each selected design improvement will provide the necessary correction, and can be introduced in the control room without creating any unacceptable human engineering discrepancies because of significant contribution to increased risk, unreviewed safety questions, or situations in which a temporary reduction in safety could occur. Improvements that are introduced should be coordinated with changes resulting from other improvement programs such as SPDS, operator training, new instrumentation (Reg. Guide 1.97, Rev. 2), and upgraded emergency operating procedures.

Documentation and NRC Review

1. All licensees shall submit a program plan within two months of the start of the control room review that describes how items 1, 2 and 3 above will be accomplished. NRC approval is not required before licensees conduct their reviews.

2. Selected licensees will undergo an in-progress audit by the NRR human factors staff based on the program plans and advice from resident inspectors.

3. All licensees shall submit a summary report outlining proposed control room changes. The report will also provide a summary justification for human engineering discrepancies with safety significance to be left uncorrected or partially corrected.

4. Within two weeks after receipt of the licensee's summary report, the NRC will inform the licensee whether it will conduct a pre-implementation onsite audit. The decision will be based on the content of the program plan, summary report, and results of NRR in-progress audits if any. The licensee selection for pre-implementation audit may or may not include licensees selected for in-progress audits under paragraph 2.

5. For control rooms selected for pre-implementation onsite audit, within one month after receipt of the summary report, the NRC will conduct:

   a. A pre-implementation audit of proposed modifications (e.g., equipment additions, deletions and relocations, and proposed modifications).

   b. An audit of the justification for those human engineering discrepancies of safety significance to be left uncorrected or only partially corrected.

   The audit will consist of a review of licensee's record of the control room reviews, discussions with the licensee review team, and usually a control room visit. Within a month after this onsite audit, NRC will issue its safety evaluation report (SER).

6. For control rooms for which NRC does not perform a pre-implementation onsite audit, NRC will conduct a review and issue its SER within two

months after receipt of the licensee's summary report. The review shall be similar to that conducted for pre-implementation plants under paragraph 5 above, except that it may or may not include a specific audit. The SER shall indicate whether, based on the review carried out, changes in the licensee's modification plan are needed to assure operational safety. Flexibility is considered in the control room review, because certain control board discrepancies can be overcome by techniques not involving control board changes. These techniques could include improved procedures, improved training, or the SPDS.

7. The following approach will be used for OL review. For OL applications with SSER dates prior to June 1983, licensing may be based on either a Preliminary Design Assessment or a Control Room Design Review (CRDR) at the applicant's option. However, applicants who choose the Preliminary Design Assessment option are required to perform a CRDR after licensing. For applications with SSER dates after June 1983, Control Room Design Review will be required prior to licensing.

Integration

Prompt implementation of an SPDS is a design goal and of primary importance. The schedule for implementing SPDS should not be impacted by schedules for the control room design review and development of symptom-oriented emergency operating procedures. For this reason, licensees should develop and propose an integrated schedule for implementation in which the SPDS design is an input to the other initiatives. If reasonable, this schedule should be accepted by NRC.

Reference Documents

NUREG-0585	--	States that licensees should conduct review.
NUREG-0660, Rev. 1	--	States that NRR will require reviews for operating reactors and operating licensee applicants.
NUREG-0700	--	Final guidelines for CRDR.
NUREG-0737	--	States that requirement was issued June, 1980, final guidance not yet issued.
NUREG-0801	--	October 1981 draft for comment; staff evaluation criteria.

REGULATORY GUIDE 1.97

6. APPLICATION TO EMERGENCY RESPONSE FACILITIES

Curr nt Regulatory Requirements

No licensee action is required.

Functional Statement

Regulatory Guide 1.97 provides data to assist control room operators in preventing and mitigating the consequences of reactor accidents.

Recommended Requirements

1. Control Room

Provide measurements and indication of Type A, B, C, D, E variables listed in Regulatory Guide 1.97 (Rev. 2). Individual licensees may take exceptions based on plant-specific design features. BWR incore thermocouples and continuous offsite dose monitors are not required pending their further development and consideration as requirements. It is acceptable to rely on currently installed equipment if it will measure over the range indicated in Regulatory Guide 1.97 (Rev. 2), even if the equipment is presently not environmentally qualified. Eventually, all the equipment required to monitor the course of an accident would be environmentally qualified in accordance with the pending Commission rule on environmental qualification.

Provide reliable indication of the meteorological variables (wind direction, wind speed, and atmospheric stability) specified in Regulatory Guide 1.97 (Rev. 2) for site meteorology. No changes in existing meteorological monitoring systems are necessary if they have historically provided reliable indication of these variables that are representative of meteorological conditions in the vicinity of the plant site. Information on meteorological conditions for the region in which the site is located shall be available via communication with the National Weather Service.

2. Technical Support Center (TSC)

The Type A, B, C, D, E variables that are essential for performance of TSC functions shall be indicated in the TSC.

a. BWR incore thermocouples and continuous offsite dose monitors are not required pending their further development and consideration as requirements.

b. The indicators and associated circuitry shall be of reliable design but need not meet Class 1E, single-failure or seismic qualification requirements.

3. Emergency Operations Facility (EOF)

   a. Those primary indicators needed to monitor containment conditions and releases of radioactivity from the plant shall be provided in the EOF.

   b. The EOF data indications and associated circuitry shall be of reliable design but need not meet Class 1E, single-failure or seismic qualification requirements.

Documentation and NRC Review

NRC review is not a prerequisite for implementation. Staff review will be in the form of an audit that will include a review of the licensee's method of implementing Regulatory Guide 1.97 (Rev. 2) guidance and the licensee's supporting technical justification of any proposed alternatives.

The licensee shall submit a report describing how it meets these requirements. The submittal should include documentation which may be in the form of a table that includes the following information for each Type A, B, C, D, E variable shown in Regulatory Guide 1.97 (Rev. 2):

(a) instrument range
(b) environmental qualification (as stipulated in guide or state criteria)
(c) seismic qualification (as stipulated in guide or state criteria)
(d) quality assurance (as stipulated in guide or state criteria)
(e) redundancy and sensor(s) location(s)
(f) power supply (e.g., Class 1E, non-Class 1E, battery backed)
(g) location of display (e.g., control room board, SPDS, chemical laboratory)
(h) schedule (for installation or upgrade)

Deviations from the guidance in Regulatory Guide 1.97 (Rev. 2) should be explicitly shown, and supporting justification or alternatives should be presented.

7. UPGRADE EMERGENCY OPERATING PROCEDURES (EOPs)

Current Regulatory Requirements

NUREG-0737, Item I.C.1, which has been approved by the Commission for implementation.

Functional Statement

Symptom-based emergency operating procedures will improve human reliability and the ability to mitigate the consequences of a broad range of initiating events and subsequent multiple failures or operator errors.

Recommended Requirements

1. In accordance with NUREG-0737, Item I.C.1, reanalyze transients and accidents and prepare Technical Guidelines. These analyses will identify operator tasks, and information and control needs. The analyses also serve as the basis for integrating upgraded emergency operating procedures and the control room design review and verifying the SPDS design.

2. Upgrade EOPs to be consistent with Technical Guidelines and an appropriate procedure Writer's Guide.

3. Provide appropriate training of operating personnel on the use of upgraded EOPs prior to implementation of the EOPs.

4. Implement upgraded EOPs.

Documentation and NRC Review

1. Submit Technical Guidelines to NRC for review. NRC will perform a pre-implementation review of the Technical Guidelines and the Writer's Guide. Within two months of receipt of the Technical Guidelines and Writer's Guide, NRC will advise the licensees of their acceptability.

2. Each licensee shall submit to NRC a procedures generation package at least three months prior to the date it plans to begin formal operator training on the upgraded procedures. NRC approval of the submittal is not necessary prior to upgrading and implementing the EOPs. The procedures generation package shall include:

   a. Plant-Specific Technical Guidelines -- plant-specific guidelines for plants not using generic technical guidelines. For plants using generic technical guidelines, a description of the planned method for developing plant specific EOPs from the generic guidelines, including plant specific information.

   b. A Writer's Guide that details the specific methods to be used by the licensee in preparing EOPs based on the Technical Guidelines.

c. A description of the program for validation of the EOPs.

d. A brief description of the training program for the upgraded EOPs.

3. All procedures generation packages will be reviewed. On an audit basis for selected facilities, upgraded EOPs will be reviewed. The details and extent of this review will be based on the quality of the procedures generation packages submitted to NRC. A sampling of ugpraded EOPs will be reviewed for technical adequacy in conjunction with the NRC Reactor Inspection Program.

Reference Documents

NUREG-0660, Item I.C.1, I.C.8, I.C.9

NUREG-0799

8. EMERGENCY RESPONSE FACILITIES

Current Regulatory Requirements

10 CFR 50.47(b)(6) (for Operating License applicants) -- Requirement for prompt communications among principal response organizations and to emergency personnel and to the public.

10 CFR 50.47(b)(8) -- Requirement for emergency facilities and equipment to support emergency response.

10 CFR 50.47(b)(9) -- Requirement that adequate methods, systems and equipment for assessing and monitoring actual or potential offsite consequences of a radiological emergency condition are in use.

10 CFR 50.54(q) (for Operating Reactors) -- Same requirement as 10 CFR 50.47(b) plus 10 CFR 50, Appendix E.

10 CFR 50, Appendix E, Paragraph IV.E
Requirement for:

"1. Equipment at the site for personnel monitoring;

"2. Equipment for determining the magnitude of and for continuously assessing the impact of the release of radioactive materials to the environment;

"3. Facilities and supplies at the site for decontamination of onsite individuals;

"4. Facilities and medical supplies at the site for appropriate emergency first aid treatment;

"5. Arrangements for the services of physicians and other medical personnel qualified to handle radiation emergencies on site;

"6. Arrangements for transportation of contaminated injured individuals from the site to specifically identified treatment facilities outside the site boundary;

"7. Arrangements for treatment of individuals injured in support of licensed activities on the site at treatment facilities outside the site boundary;

"8. A licensee onsite technical support center and a licensee near-site emergency operations facility from which effective direction can be given and effective control can be exercised during an emergency;

"9. At least one onsite and one offsite communications system; each system shall have a backup power source.

All communication plans shall have arrangements for emergencies, including titles and alternates for those in charge at both ends of the communication links and the primary and backup means of communication. Where consistent with the function of the governmental agency, these arrangements will include:

"a. Provision for communications with contiguous State/local governments within the plume exposure pathway (emergency planning zone) EPZ. Such communications shall be tested monthly.

"b. Provision for communications with Federal emergency response organizations. Such communications systems shall be tested annually.

"c. Provision for communications among the nuclear power reactor control room, the onsite technical support center, and the near-site emergency operations facility; and among the nuclear facility, the principal State and local emergency operations centers, and the field assessment teams. Such communications systems shall be tested annually.

"d. Provision for communications by the licensee with NRC Headquarters and the appropriate NRC Regional Office Operations Center from the nuclear power reactor control room, the onsite technical support center, and the near-site emergency operations facility. Such communications shall be tested monthly."

Within this section on emergency response facilities, the Technical Support Center (TSC), Operational Support Center (OSC) and Emergency Operations Facility (EOF) are addressed separately in terms of their functional statements and recommended requirements. The subsections on Documentation and NRC Review and Reference Documents that follow the EOF discussion apply to this entire section on emergency response facilities.

Technical Support Center (TSC)

Functional Statement

The TSC is the onsite technical support center for emergency response. When activated, the TSC is staffed by predesignated technical, engineering, senior management, and other licensee personnel, and five predesignated NRC personnel. During periods of activation, the TSC will operate uninterrupted to provide plant management and technical support to plant operations personnel, and to relieve the reactor operators of peripheral duties and communications not directly related to reactor system manipulations. The TSC will perform EOF functions for the Alert Emergency class and for the Site Area Emergency class and General Emergency class until the EOF is functional.

Recommended Requirements

The TSC will be:

1. Located within the site protected area so as to facilitate necessary interaction with control room, OSC, EOF and other personnel involved with the emergency.

2. Sufficient to accommodate and support NRC and licensee predesignated personnel, equipment and documentation in the center.

3. Structurally built in accordance with the National Uniform Building Code.

4. Environmentally controlled to provide room air temperature, humidity and cleanliness appropriate for personnel and equipment.

5. Provided with radiological protection and monitoring equipment necessary to assure that radiation exposure to any person working in the TSC would not exceed 5 rem whole body, or its equivalent to any part of the body, for the duration of the accident.

6. Provided with reliable voice and data communications with the control room and EOF and reliable voice communciations with the OSC, NRC Operations Centers and state and local operations centers.

7. Capable of reliable data collection, storage, analysis, display and communication sufficient to determine site and regional status, determine changes in status, forecast status and take appropriate actions. The following variables shall be available in the TSC:

   (a) the variables in the appropriate Table 1 or 2 of Regulatory Guide 1.97 (Rev. 2) that are essential for performance of TSC functions; and

   (b) the meteorological variables in Regulatory Guide 1.97 (Rev. 2) for site vicinity and National Weather Service data available by voice communication for the region in which the plant is located.

Principally those data must be available that would enable evaluating incident sequence, determining mitigating actions, evaluating damages and determining plant status during recov.ry operations.

8. Provided with accurate, complete and current plant records (drawings, schematic diagrams, etc.) essential for evaluation of the plant under accident conditions.

9. Staffed by sufficient technical, engineering, and senior designated licensee officials to provide needed support, and be fully operational within approximately 1 hour after activation.

10. Designed taking into account good human factors engineering principles.

Operational Support Center (OSC)

Functional Statement

When activated, the OSC will be the onsite area separate from the control room where predesignated operations support personnel will essemble. A predesignated licensee official shall be responsible for coordinating and assigning the personnel to tasks designated by control room, TSC or EOF personnel.

Recommended Requirements

The OSC will be:

1. Located onsite to serve as an assembly point for support personnel and to facilitate performance of support functions and tasks.

2. Capable of reliable voice communications with the control room, TSC and EOF.

Emergency Operations Facility (EOF)

Functional Statement

The EOF is a licensee controlled and operated facility. The EOF provides for management of overall licensee emergency response, coordination of radiological and environmental assessment, determination of recommended public protective actions, and coordination of emergency response activities with Federal, State, and local agencies.

When the EOF is activated, it will be staffed by predesignated emergency personnel identified in the emergency plan. A designated senior licensee official will manage licensee activities in the EOF.

Facilities shall be provided in the EOF for the acquisition, display, and evaluation of radiological and meteorological data and containment conditions necessary to determine protective measures. These facilities will be used to evaluate the magnitude and effects of actual or potential radioactive releases from the plant and to determine dose projections.

Recommended Requirements

The EOF will be:

1. Located and provided with radiation protection features as described in Table 1 (previous guidance approved by the Commission) and with appropriate radiological monitoring systems.

2. Sufficient to accommodate and support Federal, State, local and licensee predesignated personnel, equipment and documentation in the EOF.

3. Structurally built in accordance with the National Uniform Building Code.

4. Environmentally controlled to provide room air temperature, humidity and cleanliness appropriate for personnel and equipment.

5. Provided with reliable voice and data communications facilities to the TSC and control room, and reliable voice communication facilities to OSC and to NRC, State and local emergency operations centers.

6. Capable of reliable collection, storage, analysis, displays and communication of information on containment conditions, radiological releases and meteorology sufficient to determine site and regional status, determine changes in status, forecast status and take appropriate actions. Variables from the following categories that are essential to EOF functions shall be available in the EOF:

   (a) variables from the appropriate Table 1 or 2 Regulatory Guide 1.97 (Rev. 2), and

(b) the meteorological variables in Regulatory Guide 1.97 (Rev. 2) for site vicinity and regional data available via communication from the National Weather Service.

7. Provided with up to date plant records (drawings, schematic diagrams, etc.), procedures, emergency plans and environmental information (such as geophysical data) needed to perform EOF functions.

8. Staffed in accordance with Table 2 (previous guidance approved by the Commission). Reasonable exceptions to the 30-minute and 1-hour time limits for staffing should be justified and will be considered by NRC staff.

9. Provided with industrial security when it is activated to exclude unauthorized personnel and when it is idle to maintain its readiness.

10. Designed taking into account good human factors engineering principles.

Documentation and NRC Review

The conceptual design for emergency response facilities (TSC, OSC, and EOF) have been submitted to NRC for review. In many cases, the lack of detail in these submittals has precluded an NRC decision of acceptability. Some designs have been disapproved because they clearly did not meet the intent of the applicable regulations. NRC does not intend to approve each design prior to implementation, but rather has provided in this document those "recommended requirements" which should be satisfied. These recommended requirements provided a degree of flexibility within which licensees can exercise management prerogatives in designing and building emergency response facilities (ERF) that satisfy specific needs of each licensee. The foremost consideration regarding ERFs is that they provide adequate capabilities of licensees to respond to emergencies. NUREG guidance on ERFs has been intended to address specific issues which the Commission believes should be considered in achieving improved capabilities.

Licensees should assure that the design of ERFs satisfies these basic requirements. Exemptions from or alternative methods of implementing these requirements should be discussed with NRC staff and in some cases could require Commission approval. Licensees should continue work on ERFs to complete them according to schedules that will be negotiated on a plant-specific basis. NRC will conduct appraisals of completed facilities to verify that these requirements have been satisfied and that ERFs are capable of performing their intended functions. Licensees need not document their actions on each specific item contained in NUREG-0696 or 0814.

Reference Documents (Emergency Response Facilities)

10 CFR 50.47(b) -- Requirements for emergency facilities and equipment for OLs.

10 CFR 50.54(q) and Appendix E, Paragraph IV.E -- Requirements for emergency facilities and equipment for ORs.

NUREG-0660 -- Description of and implementation schedule for TSC, OSC and EOF.

Eisenhut letter to power reactor licensees 9/13/79 -- Request for commitment to meet requirements.

Denton letter to power reactor licensees 10/30/79 -- Clarification of requirements
and implementation schedule.

Eisenhut letter to power reactor licensees 4/25/80 -- Clarification of requirements.

NUREG-0654 -- Radiological Emergency Response Plans

NUREG-0696 -- Functional criteria for emergency response facilities.

NUREG-0737 -- Guidance on meteorological monitoring and dose assessment.

Eisenhut letter to power reactor license 2/18/81 -- Commission approved guidance
on location, habitability and staff for emergency facilities. Request and deadline for submittal of conceptual design of facilities.

NUREG-0814 (Draft Report for Comment) -- Methodology for evaluation of emergency
response facilities.

NUREG-0818 (Draft Report for Comment) -- Emergency Action Levels

Reg. Guide 1.97 (Rev. 2) -- Guidance for variables to be used in selected emergency response facilities.

COMJA-80-37, January 21, 1981 -- Commission approval guidance on EOF location and habitability.

Secretary memorandum S81-19, February 19, 1981 -- Commission approval of NUREG-0696 as general guidance only.

TABLE 1

EMERGENCY OPERATIONS FACILITY

Option 1 Two Facilities	Option 2 One Facility
A. Close-in Primary: Reduce Habitability*	o At or Beyond 10 miles.
o within 10 miles o protection factor = 5 o ventilation isolation with HEPA (no charcoal)	o No special protection factor. o If beyond 20 miles, specific approval required by the Commission, and some provision for NRC site team closer to site. o Strongly recommended location be coordinated with offsite authorities.
B. Backup EOF	
o between 10-20 miles o no separate, dedicated facility o arrangements for portable backup equipment o strongly recommended location be coordinated with offsite authorities o continuity of dose projection and decision making capability	

For both Options:

- located outside security boundary
- space for about 10 NRC employees
- none designated for severe phenomena, e.g., earthquakes

*Habitability requirements are only for the part of the EOF in which dose assessments communications and decision making take place.

If a utility has begun construction of a new building for an EOF that is located with 5 miles, that new facility is acceptable (with less than protection factor of 5 and ventilation isolation and HEPA) provided that a backup EOF similar to "B" in Option 1 is provided.

TABLE

MINIMUM STAFFING REQUIREMENTS FOR NRC LICENSEES FOR NUCLEAR POWER PLANT EMERGENCIES

Major Functional Area	Major Tasks	Position Title or Expertise	Capability for Additions: On Shift*	30 min.	60 min.
Plant Operations and Assessment of Operational Aspects		Shift supervisor (SRO)	1	--	--
		Shift foreman (SRO)	1	--	--
		Control-room operators	2	--	--
		Auxiliary operators	2		
Emergency Direction and Control (Emergency Coordinator)***		Shift technical advisor, shift supervisor, or designated facility manager	1**	--	--
Notification/ Communication****	Nofity licensee, state local, and federal personnel & maintain communication		1	1	2
Radiological Accident Assessment and Support of Operational Accident Assessment	Emergency operations facility (EOF) director	Senior manager	--	--	1
	Offsite dose assessment	Senior health physics (HP) expertise	--	1	--
	Offsite surveys		--	2	2
	Onsite (out-of-plant)		--	1	1
	Inplant surveys	HP technicians	1	1	1
	Chemistry/radio-chemistry	Rad/chem technicians	1	--	1

NOTE: Source of this table is NUREG-0654, "Functional Criteria for Emergency Response Facilities."

TABLE 2 (Co[illegible])

Major Functional Area	Major Tasks	Position Title or Expertise	Capability for Additions On Shift*	30 min.	60 min.
Plant System Engineering, Repair and Corrective Actions	Technical support	Shift technical advisory	1	--	--
		Core/thermal hydraulics	--	1	--
		Electrical	--	--	1
		Mechanical	--	--	1
	Repair and corrective actions	Mechanical maintenance/	1**	--	1
		Radwaste operator			1
		Electrical maintenance/	1**	1	1
		instrument and control		1	--
		(I&C) technician	--	1	--
Protective Actions (In-Plant)	Radiation protection: a. Access control b. HP Coverage for repair, corrective actions, search and rescue first-aid, & firefighting c. Personnel monitoring d. Dosimetry	HP technicians	2**	2	2
Firefighting	--	--	Fire brigade per technical specification	Local support	
Rescue Operations and First-Aid	--	--	2**	Local support	

TABLE 2 (Co.   d)

Major Functional Area	Major Tasks	Position Title or Expertise	Capability for Additions On Shift*	30 min.	60 min.
Site Access Control and Personnel Accountability	Security, firefighting communications, personnel accountability	Security personnel	All per security plan		
		Total	10	11	15

*For each unaffected nuclear unit in operation, maintain at least one shift foreman, one control-room operator, and one auxiliary operator except that units sharing a control room may share a shift foreman if all functions are covered.

**May be provided by shift personnel assigned other functions.

***Overall direction of facility response to be assumed by EOF director when all centers are fully manned. Director of minute-to-minute facility operations remains with senior manager in technical support center or control room.

****May be performed by engineering aide to shift supervisor.

Attachment 10(B) - 5

NUREG/CR-2644
ENICO-1110

An Assessment of Offsite, Real-Time Dose Measurement Systems for Emergency Situations

Prepared by W. J. Maeck, L. G. Hoffman, B. A. Staples, J. H. Keller

Exxon Nuclear Idaho Co., Inc.

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U.S. Nuclear Regulatory Commission

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ABSTRACT

An evaluation is made of the effectiveness of fixed, real-time monitoring systems around nuclear power stations in determining the magnitude of unmonitored releases. The effects of meteorological conditions on the accuracy with which the magnitude of unmonitored releases is determined and the uncertainties inherent in defining these meteorological conditions are discussed. The number and placement of fixed field detectors in a system is discussed, and the data processing equipment required to convert field detector output data into release rate information is described. Cost data relative to the purchase and installation of specific systems are given, as well as the characteristics and information return for a system purchased at an arbitary cost.

SUMMARY

The Nuclear Regulatory Commission has been considering a requirement that each operating commercial nuclear power station be fitted with an offsite real-time emergency monitoring system. Currently, several power stations have installed, or are in the process of installing, monitoring systems of varying degrees of complexity and sophistication.

Prior to deciding whether to require all stations to install an offsite real-time emergency monitoring system, the NRC requested an independent evaluation of the usefullness of such a system and an assessment of the validity of the information obtained from the system. The information provided by this study will be used to aid the NRC in their determination of whether or not to require that fixed offsite real-time emergency monitoring systems be installed at all operating and planned commercial nuclear power stations.

This study addresses several aspects of the offsite real-time emergency monitoring system concept. The primary items receiving attention in this study are:

1. The ability of a fixed real-time monitoring system to detect and quantify monitored and unmonitored releases.

2. The ability of the system to detect and quantify an unmonitored release in the presence of a known release.

3. An assessment of the uncertainties associated with estimating the magnitude of an unmonitored release.

4. The number of stations required to detect a release and the uncertainty associated with the detected value.

5. The availability, cost, and the instrumentation requirements for a system.

An augmented effort of the study was to determine the characteristics and information return that might be obtained from a close-in (0.5 mile) system with capital costs limited to $500,000.

A matrix approach was used in this evaluation in which the three major parameters were, 1) the measurement range of the detector, 2) the accuracy of the final results, and 3) the costs.

The general conclusions from this study are presented below. The uncertainty estimates are based on the use of simple error analyses of the meteorological expressions required to describe plume shapes and atmospheric transport.

1. While a ring of detectors around a nuclear power station can provide the means for monitoring releases; the number of stations required for two detectors to provide information within a factor of 5 of each other can be as large as 50 or more for one installation.

2. The use of short-time (15 min) data from a fixed offsite monitoring system to project downwind dose rates is a complex and highly uncertain process. Based on our study the uncertainty associated with a projected value is at least a factor of 10 or more.

3. The use of a fixed offsite monitoring system to determine the magnitude of an unmonitored release in the presence of a monitored release is highly questionable. Depending on the ratio of the unmonitored release to the monitored release, uncertainties of factors of 25 and 50 are common.

4. Several vendors of monitoring equipment were contacted relative to cost and performance characteristics of the available instrumentation. In addition, we contacted several power stations and state agencies involved in the installation of fixed real-time environmental monitoring systems. While the cost factors

for the instrumentation were relatively fixed, the installation costs were highly variable. Based on this study the cost per monitoring station ranges from $25,000 to $65,000. Depending upon the specific site characteristics the cost for a 32 station system could easily exceed $1,000,000 while only providing data with uncertainties in the range of factors of 10 to 50.

5. The placement of a simple limited ($500,000) detector system in proximity (0.5 mi) to a reactor may not provide reliable information in the case of an emergency for several reasons. Of prime importance is the limited number of stations (8-16) that could be installed and the consequence that a plume might go undetected. A second serious problem, especially in the case of a BWR, is the building shine factor which could give a sufficiently high background signal to negate detection of the plume radiation.

In general, it is highly questionable that a fixed station (16-32 units) emergency monitoring system can provide sufficiently reliable technical information to be of use in a decision-making process in the event of an emergency situation.

This conclusion should not preclude consideration of the installation of such a system. A monitoring system could be used to develop site specific meterological information and could develop improved public relations with the populace. It should be emphasized, however, that the stations should be judiciously placed so as not to convey false information.

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1.0 INTRODUCTION

1.1 Background

It has been recommended that systems of offsite, real-time environmental monitors be installed around nuclear power stations.[1] The premise is that the data obtained from such a system could, when coupled with meteorological data, provide information relative to unmonitored, as well as monitored radioactive effluent releases, and provide the basis for making downwind dose rate projections during an emergency accident situation.

1.2 Objective

The purpose of this study is to evaluate this proposal and to provide information to aid the NRC in determining whether or not to require that a fixed offsite monitoring system be installed at all nuclear power stations.

The primary items considered in this study are:

1) The ability and related accuracy of a fixed real-time monitoring system to detect monitored and unmonitored releases.

2) The ability of a fixed real-time monitoring system and associated calculational methods to detect and quantify the magnitude of an unmonitored release in the presense of a known release.

3) To provide an estimate of the credibility (uncertainty) of the information associated with the estimated value of an unmonitored release.

4) To determine, using calculational methods, the number of fixed stations required to detect a release and to provide an estimate of the uncertainty in the measured dose as a function of the number of stations.

5) To provide cost data relative to the installation, operation, and maintenance of a fixed real-time monitoring system.

6) To determine the characteristics and information return for an 800 m (0.5 mile) (probably onsite) emergency system with capital cost limited to $500,000.

1.3 Evaluation Criteria

The variables to be considered in this evaluation are listed below and shown in a matrix array in Figure 1.

Range of Detector (Assume Background of 10 μR/hr)	a. (0.1 x background) to 10 R/hr b. (1.0 x background) to 10 R/hr c. (10 x background) to 10 R/hr d. (100 x background) to 10 R/hr
Accuracy of Dose to:	a. ± factor of 2 b. ± factor of 5 c. ± factor of 10 d. ± factor of 50 e. ± factor of 250
Order of Magnitude Costs for Installed System (Excluding Costs for Detectors)	a. $ 250,000 b. $ 750,000 c. $2,000,000

The following assumptions are used throughout the evaluation:

1. The detectors will be available as "off the shelf" items and will have the sensitivity to make the required measurements. Calibration procedures will be available to assure a detector response accurate to ± 25%.

2. The monitoring stations will be located within 3200 m (2 miles) of the plant and the measurements will be averaged on a 15-minute time scale. The costs of the detectors will not be considered; but costs for signal averaging, transmission, and correction for background will be included.

3. Meteorological information requirements will be those required to satisfy NUREG-0654, Regulatory Guide 1.97 and the Proposed Revision to the Regulatory Guide 1.23.

4. Computerized analysis of the dectector and meteorological input will use in-house or "off the shelf" hardware and software to provide accurate and intelligible output for use in control room decisions. For offsite, real-time monitoring system output to be intelligible, the information presented to the operator in the control room must describe in real time the significant features of the release, such as dose distribution and contours within two miles and characterization of the source. In addition, the computer analysis must provide for downwind dose prediction capability beyond two miles.

5. The source term to be evaluated will be limited to mixtures of radionuclides which are nondepositing, i.e., only the noble gases without radioactive daughters.

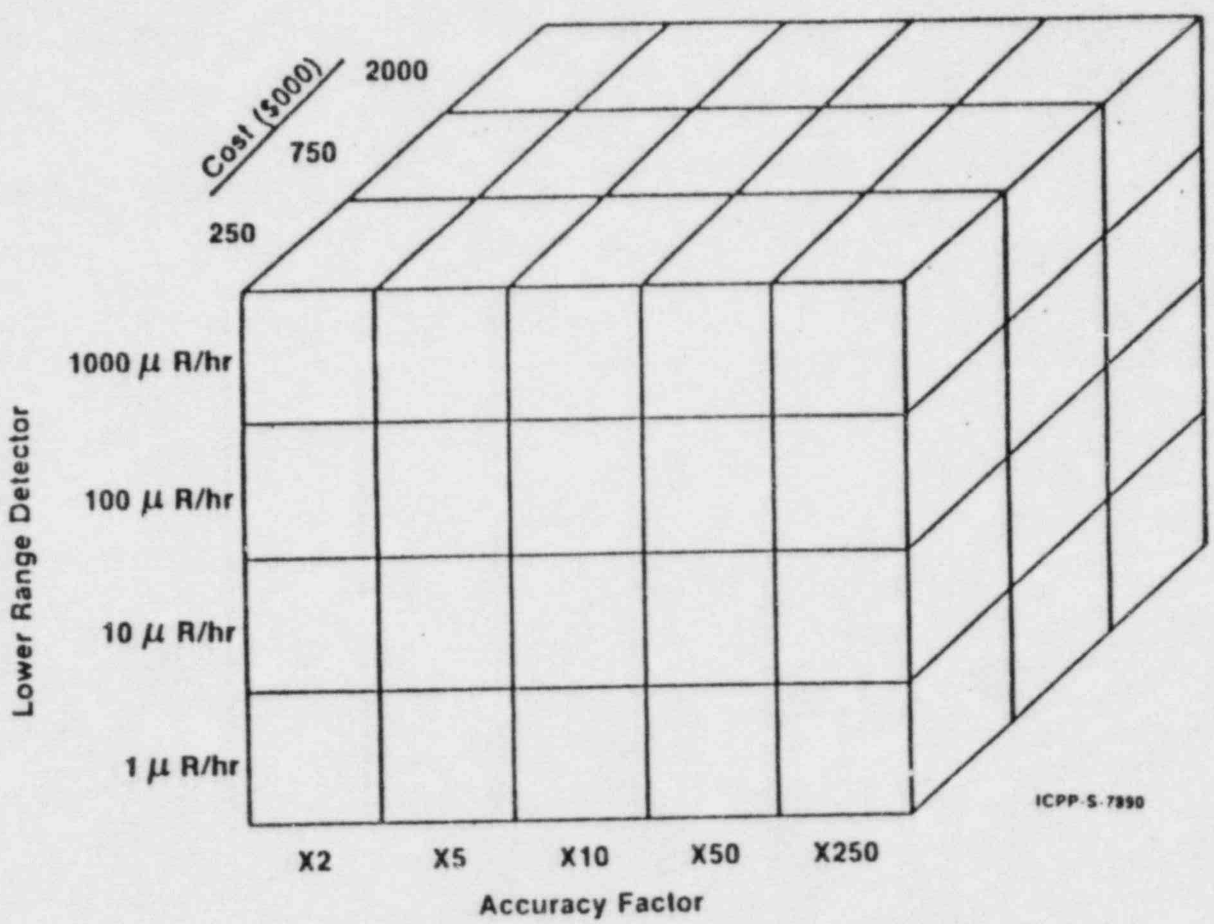

Figure 1. Matrix Parameters

2.0 QUANTIFICATION AND ASSESSMENT OF THE UNCERTAINTIES ASSOCIATED WITH THE MEASUREMENT OF AN UNMONITORED RELEASE

To provide an evaluation of the accuracy which might be obtained from a fixed offsite real-time monitoring system we used simple statistical methods of error analysis. Of particular concern was the quality and credibility of the values obtained for an unmonitored release in the presence of a known release.

The model used for this evaluation is shown in Figure 2, in which

D_B is dose related to background,
R_1 is the known or monitored release,
R_2 is the unknown release,
D_1 is the dose related to R_1,
D_2 is the dose related to R_2, and
D_T is the total dose measured by the receptor.

Thus, the total dose, D_T, is the sum of D_1, D_2 and D_B which are in some form proportional to R_1 and R_2.

$$D_T = D_1 + D_2 + D_B \quad (1)$$

$$\text{where } D_1 \propto R_1$$
$$\text{and } D_2 \propto R_2$$

To obtain a value for the unmonitored release in the presence of a known release, the following procedure is used. First, the measured value for R_1 is converted to a dose, D_1, using the equations given in Section 2.1. Second, the calculated value D_1 is subtracted from the measured value D_T to give a value for D_2. Third, the value D_2 is then converted to a value for R_2, using the same equations to obtain D_1. It is assumed that D_B is small in comparison to D_1 and D_2 and can therefore be ignored.

The following is a discussion of the errors associated with each step in the calculational procedure and an assessment of the uncertainty in the value of R_2.

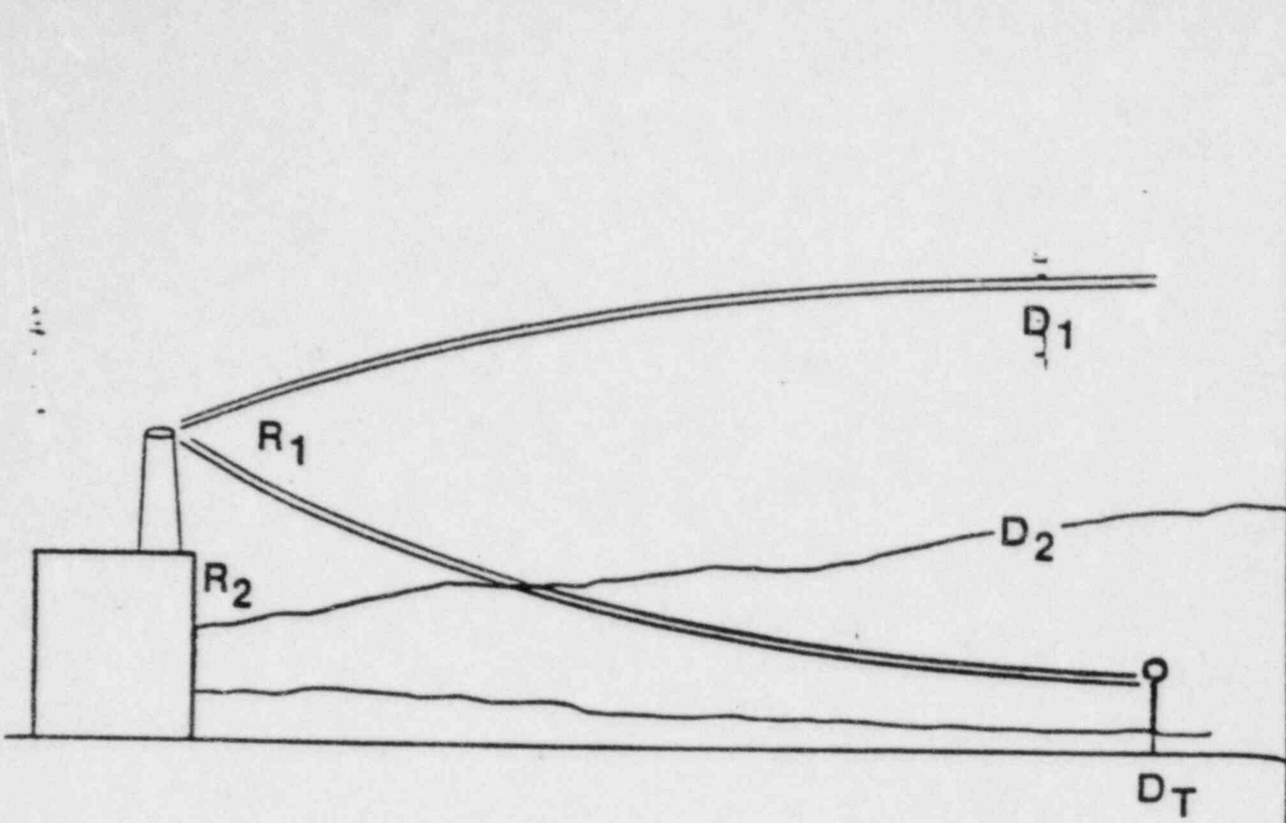

Figure 2. Model to Evaluate the Estimate of an Unmonitored Release in the Presence of a Known Release

2.1 Prediction of Downwind Atmospheric Concentration Values

The first calculational step involved in the model given in Figure 2 is conversion of the measured release R_1 to a dose D_1. The most commonly used method for calculating the exposure to a receptor involves converting the known release value to an atmospheric concentration value at some downwind distance and then integrating the concentration over the volume of the plume. The exposure is then proportional to the product of the integrated concentration and the decay energy of the radionuclides present in the plume, expressed as an exposure rate per unit release (R/hr)/(Ci/s) at 1 m/s wind speed. The detector response calculated in this study is in exposure rate. However, in the remainder of this report the authors equate exposure rate and "dose rate" as is common practice.

The atmospheric concentration value at some downwind distance is usually calculated using the Gaussian plume equation. This is an empirical diffusion formula which assumes constant wind speed, no wind shear, and flat topography. The equation for a continuous point source release is:

$$\chi(x,y,z) = \frac{QG(z)}{2\pi\sigma_y\sigma_z\bar{\mu}} \exp\left(-\frac{1}{2}(y/\sigma_y)^2\right) \qquad (2)$$

where:

- χ = atmospheric concentration at a calculated point (x,y,z) for a release point h meters above the ground, Ci/m^3
- Q = source term (release rate), Ci/seconds
- $G(z) = \exp -\frac{1}{2}((z-h)/\sigma_z)^2 + \exp -\frac{1}{2}((z+h)/\sigma_z)^2$
- σ_y = horizontal atmospheric diffusion parameter, m
- σ_z = vertical atmospheric diffusion parameter, m
- $\bar{\mu}$ = average wind speed, m/sec
- y = cross wind distance, m
- h = release height, m
- x,y,z = coordinates of the point where the concentration is calculated

In this relationship the most critical terms are the values for σ_y and σ_z. Both of these terms carry a different value for each class of atmospheric stability and downwind distance. Unfortunately, the values for σ_y and σ_z are not explicitly mathematically defined and as such must be determined empirically. A number of different field experiments have been conducted to determine σ_y and σ_z as functions of atmospheric stability conditions (weather class) and downwind distances.

Currently, the most widely used data sets for σ_y and σ_z are those based on the Pasquill-Gifford[1] model for atmospheric diffusion. Several methods have been used to establish the atmospheric stability class which must be determined prior to obtaining the values for σ_y and σ_z. One general classifying scheme is based on isolation, cloud cover, and wind speed. The standard deviation of the horizontal wind direction is also used to establish the stability class. Another method, recommended by the NRC[2] (Reg. Guide 1.23) uses the temperature gradient between 10 and 60 m (or the release height) above the ground to determine the stability classification. None of these methods are without uncertainties, and in many cases the selection of the proper atmospheric stability class may be in error by one or more classes.

Assuming an error of one stability class in the assignment process (i.e. - assigning class D for a real class E conditions), we determined the error which would be introduced in the value for χ based on the Pasquill-Gifford curves[3] for adjacent atmospheric stability classes. The effect on the value for χ at distances of 1000 m and 3000 m for release heights of 10 m and 100 m is given in Tables I and II, respectively. For a near ground-level release, the error in the predicted groundlevel average concentration could range from a factor of 2 to 10 for a one unit misassignment of the stability class. For a 100 m release the errors can be much larger.

To establish the frequency with which the stability class may be in question, four months of meteorological data for an inland nuclear power station were evaluated. For this station, both the standard deviation of the horizontal wind direction and the temperature gradient data were available on an hourly basis. An analysis of these data indicates that the assigned stability class based on these two methods differed by one class ~43% of the time, and by two classes, up to 25% of the time. The results shown in Table III indicate that the stability class assignment based on the two methods differed about 60% of the time. Thus, the downwind ground-concentration value could be in error by a factor of 5 about half of the time just from this source.

Table I. ERRORS IN X (GROUND-LEVEL AVERAGE CONCENTRATION) FOR A ONE UNIT ASSIGNMENT ERROR IN STABILITY CLASS

Release Height 10 m

True Class	Assigned Class	Error Factors: D = 1000 m, Over-predict	D = 1000 m, Under-predict	D = 3000 m, Over-predict	D = 3000 m, Under-predict
A	B	5		10	
B	A		5		10
B	C	3		4	
C	B		3		4
C	D	3		4	
D	C		3		4
D	E	2		2	
E	D		2		2
E	F	2		2	
F	E		2		2

Example: If the true stability class is C and the assigned class is D, the Gaussian plume model using Pasquill-Gifford diffusion values for class D at 3000 m over-predicts the ground-level average concentration by a factor of 4.

Table II. ERRORS IN χ (GROUND-LEVEL AVERAGE CONCENTRATION) FOR A ONE UNIT ASSIGNMENT ERROR IN STABILITY CLASS

Release Height, 100 m

		Error Factors			
		D = 1000 m		D = 3000 m	
True Class	Assigned Class	Over-predict	Under-predict	Over-predict	Under-predict
A	B	5		30	
B	A		5		30
B	C	1		6	
C	B		1		6
C	D		12	1	
D	C	12			1
D	E		15		2
E	D	15		2	
E	F		800		33
F	E	800		33	

Table III. VARIABILITY IN STABILITY CLASS ASSIGNMENT BASED ON TWO DIFFERENT MEASUREMENT METHODS

Date	No. Observation	One Class Difference	Two Class Difference
June-1974	640[a]	274 (43%)[b]	39 (6%)
July-1974	430	186 (43%)	113 (26%)
Aug.-1974	613	262 (43%)	76 (12%)
Sept.-1974	661	281 (43%)	152 (23%)

a) Number of hourly observations for which both wind variability and temperature differential data were available.

b) Percentage of the time that the stability class assignments were different.

At this point it might be well to recognize that the Gaussian plume equation only provides concentration estimates and not dose estimates. In general, the uncertainties in the dose values are not as variable as the ground-level concentration values, because the cloud gamma dose is an integrated value as opposed to a point concentration value. This fact, however, should not preclude consideration of the uncertainties in concentration values predicted by the Gaussian plume equation because the ground-level concentration values are more important with respect to the beta dose factor, the inhalation dose factor, and the ground-level concentration value for radioiodine, which may be the dominant factor in an accident case. The uncertainties associated only with the dose values will be treated in detail later in this Section.

Another item which must be considered regarding the uncertainties associated with the Gaussian plume equation and ground-level concentration values, is the validity of the primary diffusion data based on the Pasquill scheme. The basic Pasquill diffusion data were derived from tracer experiments which involved a ground-level release over very flat terrain with sampling periods of a few minutes at distances of up to about 1 km. Unfortunately through time and widespread usage, the

original nature of the experiment seems to have been forgotten by many users of the data, and the original results have been extrapolated to include elevated release points (up to 100 m) and to distances of up to 100 km. Pasquill diffusion parameters are primarily applicable to short term releases at or near ground-level over relatively short distances (1 km) and quite flat terrain.

Because of the restrictive nature of the Pasquill scheme, more recent experiments have been conducted to attempt to better quantify the diffusion parameters for the more realistic cases (i.e. hills, rough terrain, forests, metropolitan areas, and elevated releases). Some examples are given in References 4, 5, and 6. Vogt[7] and Brenk[8] have reviewed these experiments in some detail and compared the diffusion parameters derived from these experiments to each other and to Pasquill. In some cases the downwind concentration values may differ by factors of 10 to 1000, depending upon the stability class involved.

Figures 3, 4 and 5 taken from Brenk[8] give comparisons of the short-term diffusion factors for the various experimental results for stability classes A, D, and F as a function of distance, for a release height of 100 m. For class A, unstable diffusion, the data are in good agreement. However, with increasing atmospheric stability, significant differences are evident (Figures 4, 5). For class D stability at a distance of 1000 m, the difference between the Pasquill diffusion factor and the majority of the other systems is a factor of 10 to 15. At 3000 m the difference is about a factor of 5.

For class F stability there is little agreement in the diffusion factors for the various systems and differences of a factor of 100 to 1000 are common.

These data are presented not to dwell on the large differences between the various systems, but rather to emphasize the need for selecting the most applicable system for a given site. Ideally, the preferred situation is to develop site specific data. Unfortunately, experiments of this type are difficult and expensive to conduct. Brief descriptions

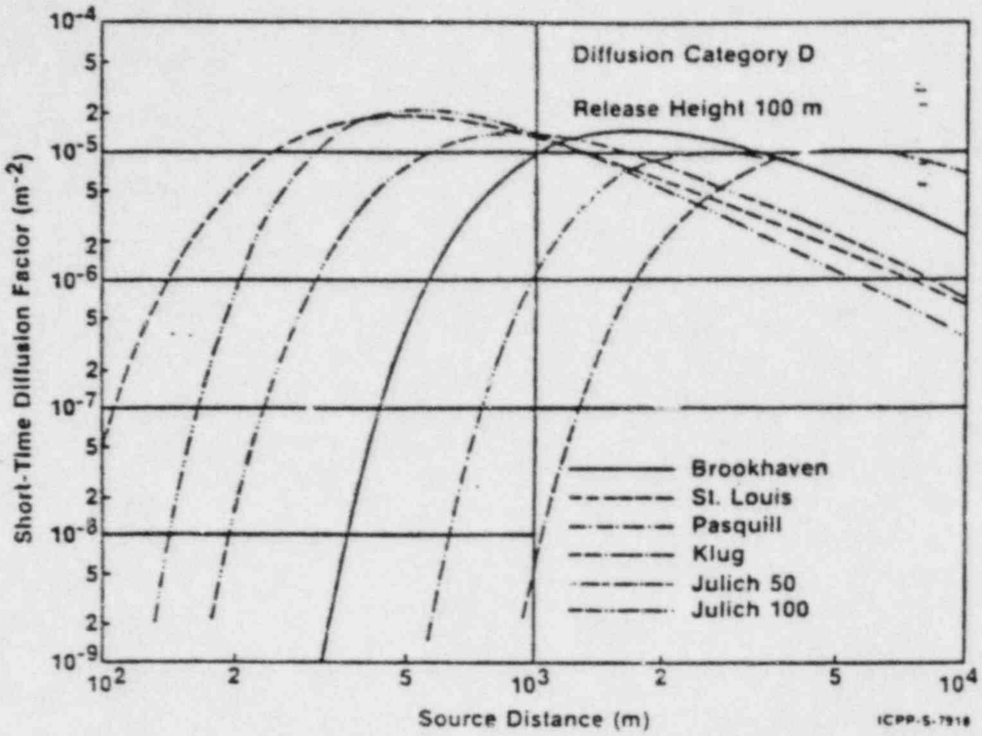

Figure 3. Comparison of Short-Term Diffusion Factors (Stability Class A) Depicted for 6 Different Diffusion Parameter Systems (From Brenk, ref. 8)

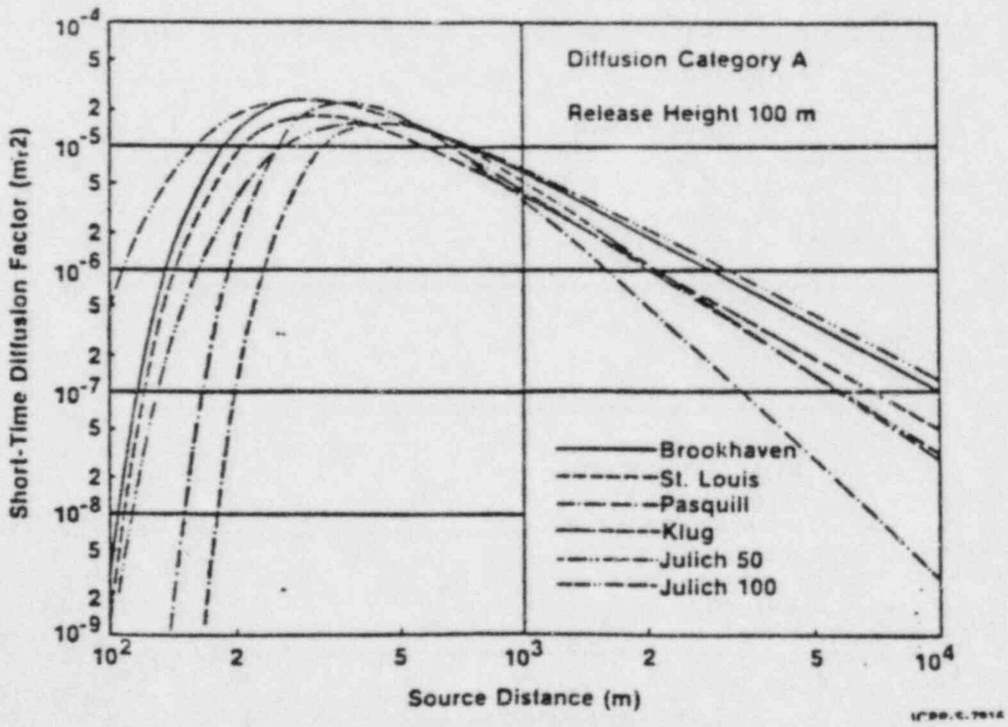

Figure 4. Comparison of Short-Term Diffusion Factors (Stability Class D) Depicted for 6 Different Diffusion Parameter Systems (From Brenk, ref. 8)

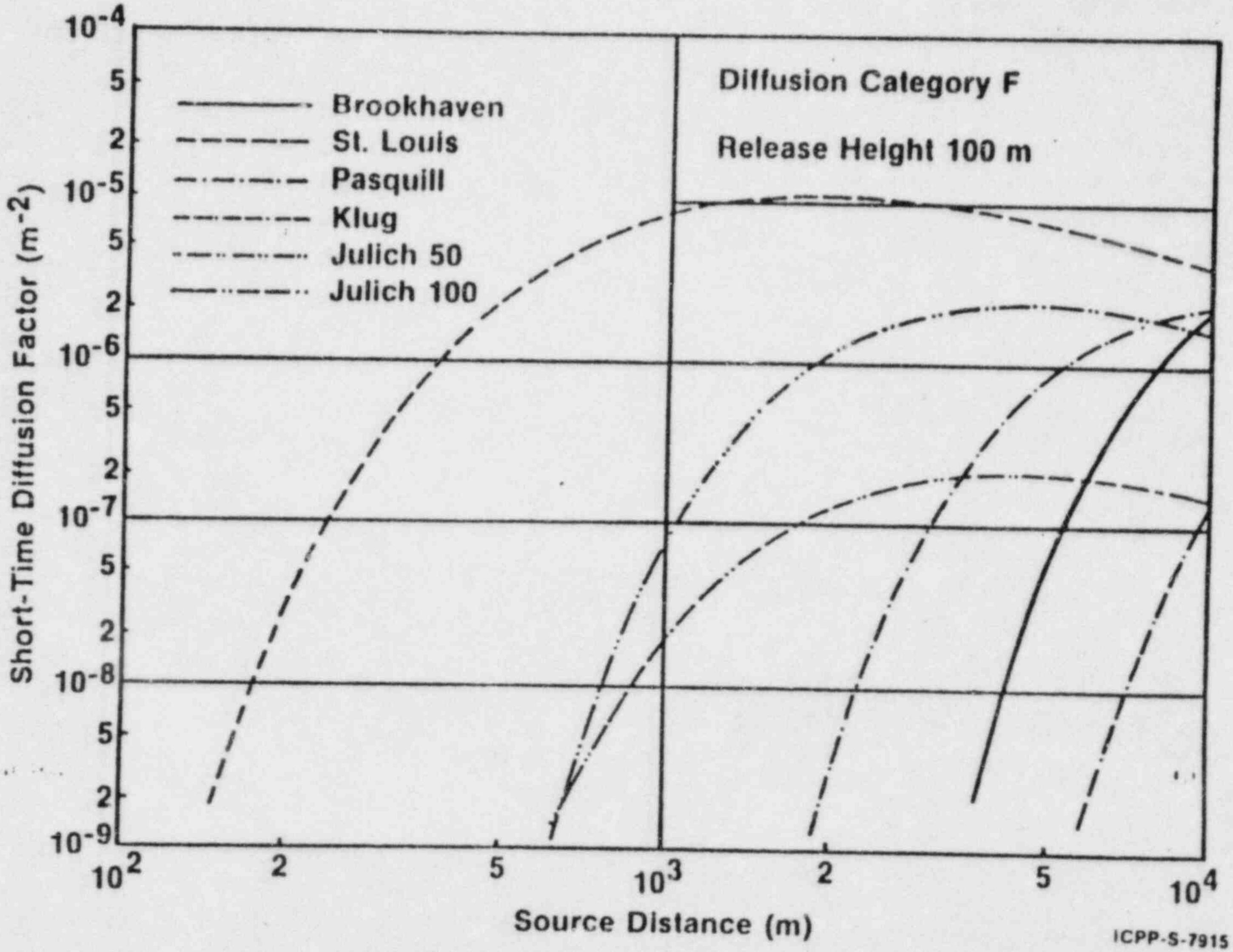

Figure 5. Comparison of Short-Term Diffusion Factors (Stability Class F) Depicted for 6 Different Diffusion Parameter Systems (From Brenk, ref. 8)

and the result and data obtained from some recent experimental programs are given in Appendix A. Included are reviews of the Savannah River ^{85}Kr experiment,[9] the ORNL assessment of the Hanford experiment[10], excerpts from a Workshop on the Evaluation of Models Used for the Environmental Assessment of Radionuclide Releases,[11] and results of a survey of programs used for radiological dose computations.[12]

Presently, it is virtually impossible to give a definitive estimate of the overall uncertainty to be associated with the prediction of downwind concentration values, especially for data related to short time periods. However, based on our study and those of others[9,10,11,12] we believe that a predicted value which may vary by a factor of 10 to 25 from the true downwind concentration is not unreasonable. Even this estimate may be low if site specific diffusion parameters are not available.

2.2 Prediction of Downwind Atmospheric Dose Values

The calculation of the cloud gamma exposure from a plume is a two-step process. First, the radionuclide concentration of the plume is calculated using the Gaussian plume dispersion equation given in Section 2.1 (Eq. 2). Second, the total cloud gamma exposure rate at the detector is calculated by using a point source approximation and integrating over the source distribution (i.e. the volume of the plume). Both components of the exposure rate calculation have been incorporated into a code developed by Science Application, Inc.,[13] which was used in this study to establish detector response values.

The assumptions and parameters used to calculate the cloud gamma values presented in this report are given below.

1. The Gaussian plume equation given in Section 2.1 (Eq. 2) was used to establish the plume dispersion and downwind concentration values. The values used for σ_y and σ_z are given in Appendix-II.

2. The cloud gamma exposure rate at a receptor was obtained by using a point source approximation and integrating over the volume of the plume. This involved an extensive numerical summation of small volume elements. Although this is a lengthy process, we believe the results are more representative than those obtained from the use of infinite or semi-infinite cloud approximations. The following is the methodology used to calculate the cloud gamma exposure rate to a receptor.

$$\text{exposure rate} \quad D\,(\frac{R}{h}) = C\,\frac{\mu a}{\rho}\,EB(\mu R)\,\Gamma \qquad (3)$$

where

$$C = 6.87 \times 10^{-5} \quad \frac{R\text{-}g\text{-}s}{MeV\text{-}h}$$

$\frac{\mu a}{\rho}$ = mass absorption coefficient for air at energy E (m^2/g)

E = energy per photon MeV/photon

$B(\mu R)$ = buildup factor

Γ = photon flux $(\frac{\text{photons}}{m^2\text{-}s})$

$$\text{photon flux } \Gamma\ (\frac{\text{photons}}{m^2\text{-}s}) = \frac{s}{4\pi r^2}\,e^{-\mu r} \qquad (4)$$

where

s = photon emission rate (photons/s)

r = distance from source (m)

μ = total linear attenuation coefficient for air (m^{-1})

The photon emission rate, s, was determined by assuming a small volume, dV, at concentration χ as follows:

$$S \text{ (photons/s)} = 3.7 \times 10^{10} \chi I_\kappa dV \qquad (5)$$

where

3.7×10^{10} = the the number of disintegrations per second per curie

χ = radionuclide concentration in the small volume element $dV (Ci/m^3)$

I_κ = number of photons of energy E per disintegration

dV = volume element considered (m^3)

Combining equations 4 and 5

$$\dot{D} \left(\frac{R}{h}\right) = \frac{2.5\ 4 \times 10^6}{4\pi r^2} \frac{\mu a}{\rho} E I_\kappa \chi e^{-\mu r} B(\mu r) dV \qquad (6)$$

Equation 6 is the contribution to the exposure rate at the detector due to the small volume element dV. The total exposure rate was obtained by integration over the volume of the plume. When using the code, $\chi\bar{\mu}/Q$ was used in equation 6 instead of χ to subsequently give results in terms of $\dot{D}\ \bar{\mu}/Q$ or exposure rate per unit release rate (R/h)/(Ci/s) at 1 meter per second wind speed.

Several calculations were made to evaluate the dose rate to a receptor as a function of stability class, distance, and release height. The dose rate as a function of distance for several stability classes for a ground level release is shown in Figure 6. At a distance of 3200 m (2 miles), the centerline dose can vary by at least four orders of magnitude over the extreme stability class range of A to F. The uncertainty in the dose as a function of adjacent stability classes can also be estimated from Figure 6. For example, at a distance of two miles the difference in the maximum centerline dose between stability class B and C is approximately 8, and between stability class C and D, approximately 3. These values are for an average gamma ray energy of ~80 keV(^{133}Xe). The differences are only slightly less for an average energy of 250 keV.

The effect of the release height on the dose rate as a function of distance for three different stability classes is shown in Figure 7. For the worst case, class F, the dose rate at short distances (500-1000 m) can vary a factor of 6-12 between a release height of 0 to 100 m. This difference decreases as a function of distance. At 3200 m the difference is approximately 2.5.

In the discussions presented up to this point, we have assumed that the centerline of the plume has passed directly over the receptor, thereby giving the maximum dose value. The probability of this happening is quite remote. The number of detectors and their placement required to give accurate dose readings will be discussed in detail in Section 3.

Based on the calculated data given in Figures 6 and 7 and the problems presented with respect to an accurate assessment of the prevailing weather class and to a knowledge of the location of the source term, it is our opinion that the calculated downwind dose value must carry an associated uncertainty of at least a factor of 10 or more.

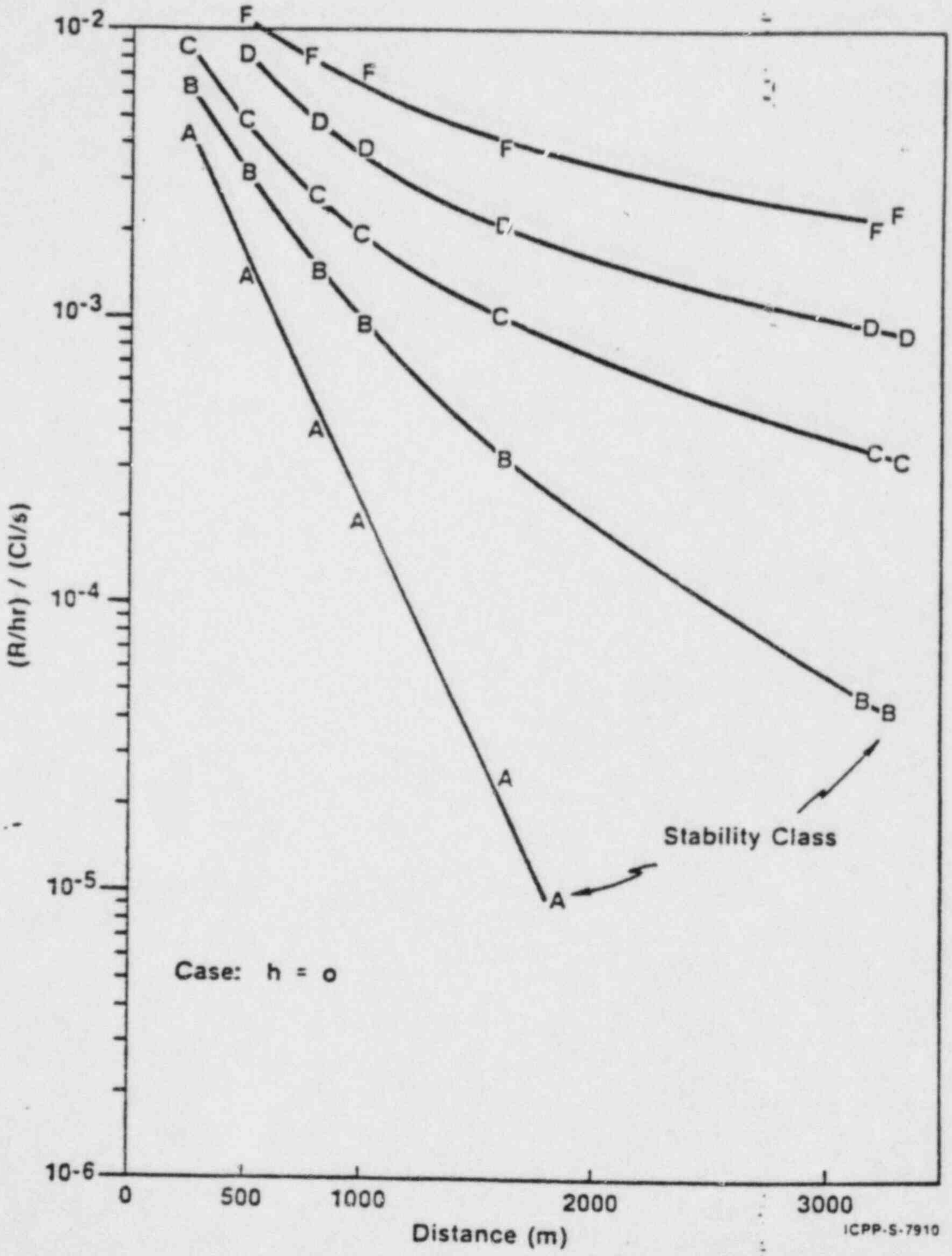

Figure 6. Projected Center Line Dose as a Function of Stability Class and Distance For a Ground Level Release

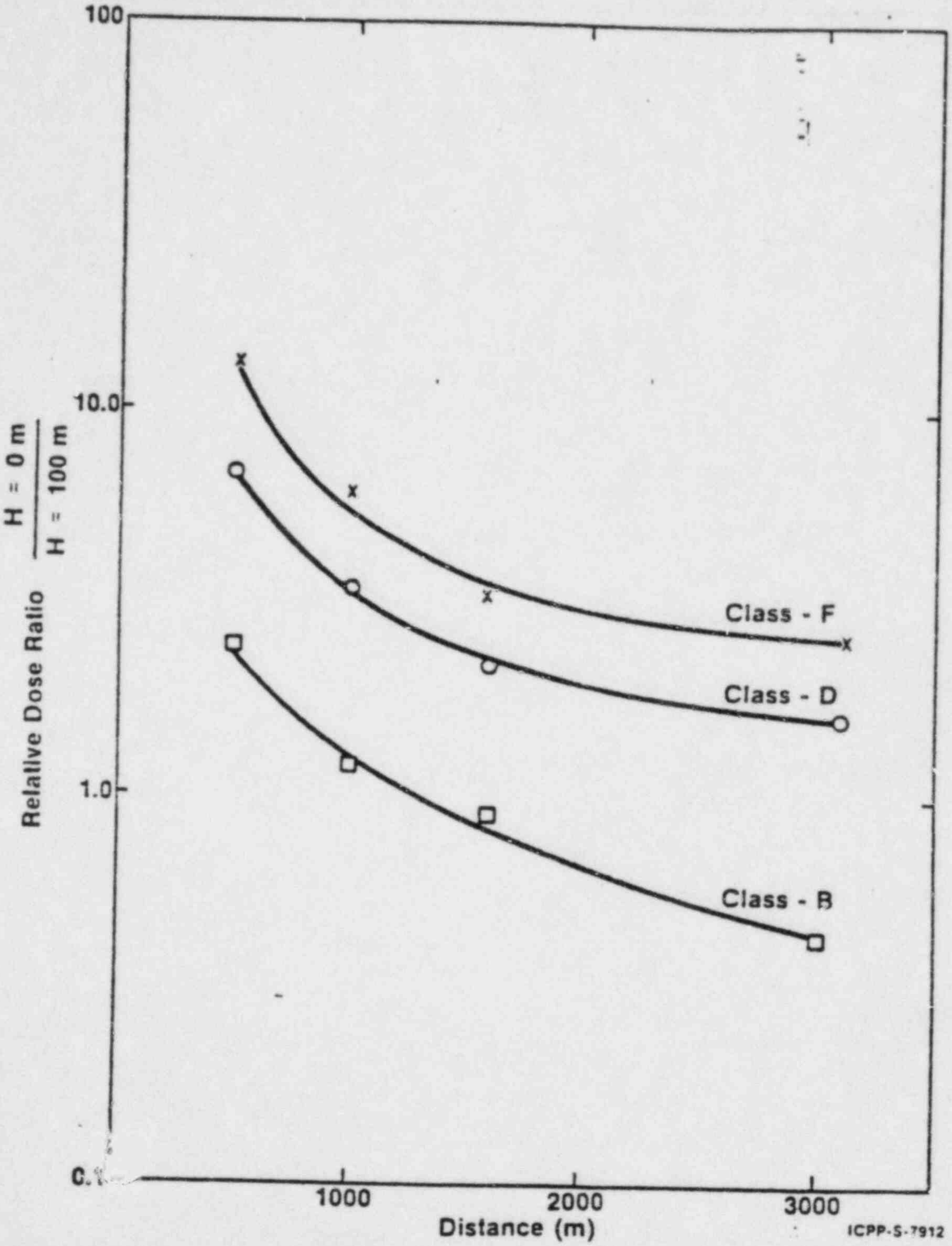

Figure 7. Effect of Release Height on Dose Rate as a Function of Distance for Stability Class B, D, and F

2.3 Uncertainties Associated with the Quantification of an Unmonitored Release

The uncertainties and range of values associated with quantifying the magnitude of an unmonitored release (R_2) in the presence of a known release (R_1) were calculated based on the model given in Figure 2 and the relationship,

$$D_T = D_1 + D_2$$

$$\text{where } D_1 \propto R_1, \text{ and}$$
$$D_2 \propto R_2.$$

The calculation of the expected error in R_2 assumed the following conditions:

1.

R_2(constant)	1	1	1
R_1(variable)	10	1	0.1

2. The uncertainties assigned to D_1 were:

± factor of 2	(200%)
± factor of 5	(500%)
± factor of 10	(1000%)
± factor of 25	(2500%)

3. The same uncertainties were assigned to D_2; however, in many cases the uncertainty associated with D_2 may be larger than D_1 because the height of the release is probably unknown.

4. No significant error was assumed in the measured dose, D_T.

5. The background contribution is small. If the background is significant with respect to the measured D_T value the resultant error will increase.

The results of the error analysis are given graphically in Figure 8 and listed in Table IV. In Figure 8, the range in the values for R_2 as a function of the ratio R_1/R_2 are given for a family of uncertainty assignments for D_1 and D_2. From this simple error analysis it is concluded that uncertainties of factors of 10 to 25 are possible for the calculated value for the unmonitored release, especially when the magnitude of the unmonitored release is equal to or smaller than the known release. For the case where the unmonitored release is large with respect to the known release the uncertainty in the unmonitored release will approach the error associated with the values for D_1 and D_2.

For example, in the case where the known release and the unmonitored release, R_1 and R_2 respectively, are of equal magnitude (in this case, 1) and the assumed uncertainty in the calculated values for D_1 and D_2 is a factor of 10, the value for R_2 can have a range of 0 to 19 for a true value of 1. For the case where the unmonitored release is 10 times larger than the known release and the uncertainty in D_1 and D_2 is a factor of 10, the value of R_2 can have a range of 0 to 11 for a true value of 1. For the case where R_2 is only one-tenth of R_1 the uncertainty in the value 1 for R_2 increases dramatically, having a range of 0 to 100 for an uncertainty of a factor of 10 in D_1 and D_2.

This error analysis only presents the range of relative values to be associated with an unmonitored release having an assigned value of 1. It does not provide an estimate of the true value of the unmonitored value. The accuracy of the true value for the unmonitored release depends on the location of the plume relative to the detector. If the plume centerline is several degrees removed from the detector, the measured value for D_T could be low by a factor of 2 to 10 depending on the proximity of the plume to the detector. This effect is discussed in detail in Section 3.

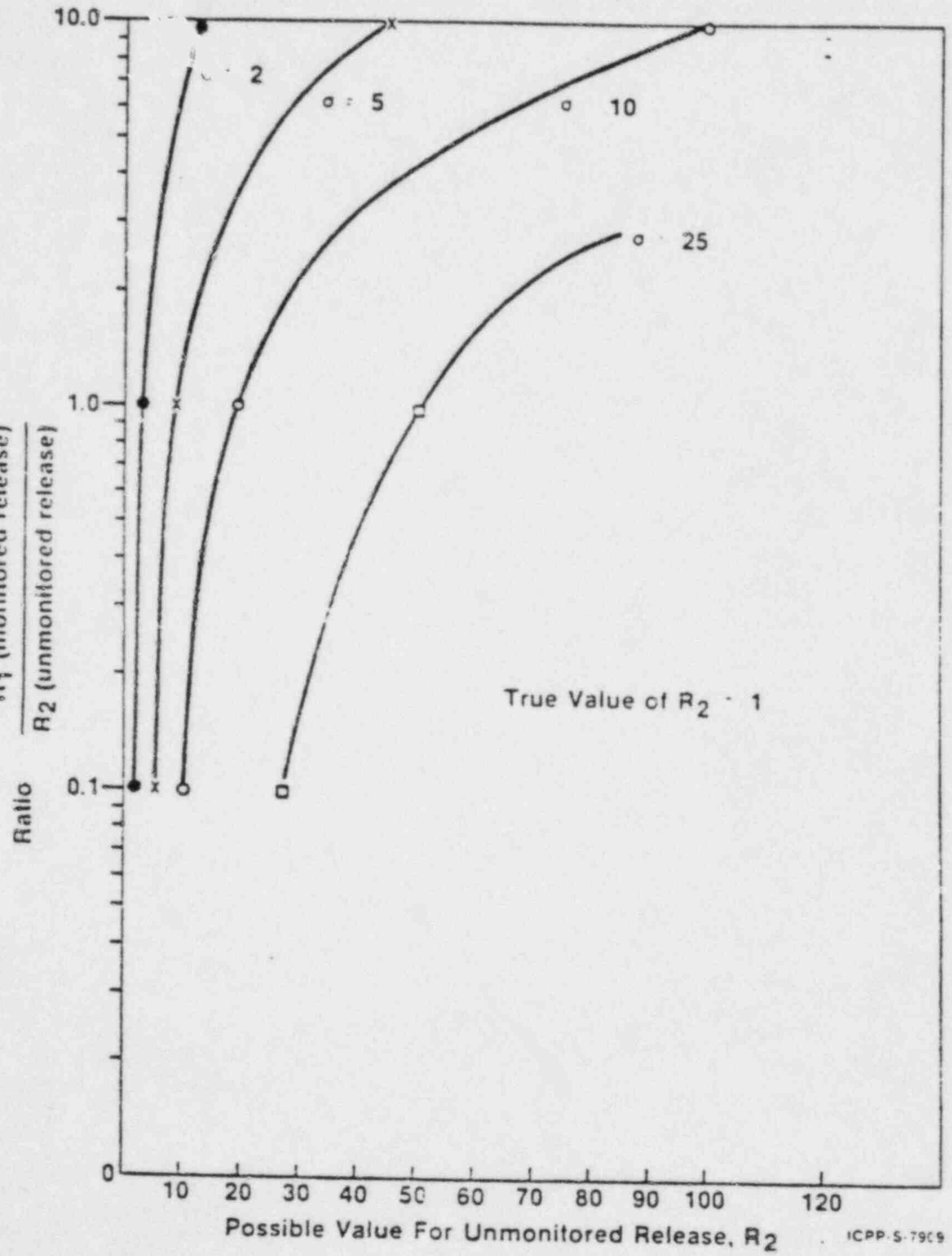

Figure 8. Uncertainty in Calculated Values of an Unmonitored Release in the Presence of a Monitored Release

Table IV RANGE OF UNCERTAINTIES WHICH CAN BE ASSOCIATED WITH AN UNMONITORED RELEASE HAVING A TRUE VALUE = 1.

CASE: 1	UNCERTAINTY D_1, D_2	RANGE IN CALCULATED VALUE OF R_2
$R_1 = 10$	200%	12 to -4.5
$R_2 = 1$	500%	45 to -7.8
$R_T = 11$	1000%	100 to -8.9
	2500%	265 to -9.6
CASE: 2		
$R_1 = 1$	200%	3 to 0
$R_2 = 1$	500%	9 to -0.6
$R_T = 2$	1000%	19 to -0.8
	2500%	49 to -0.9
CASE: 3		
$R_1 = 0.1$	200%	2.1 to 0.5
$R_2 = 1$	500%	5.4 to 0.1
$R_T = 1.1$	1000%	10.9 to 0.01
	2500%	27.4 to -0.1

3.0 DETECTOR PLACEMENT AND REQUIREMENTS

3.1 Detector Placement and Response Functions

The response functions and requirements for a ring of detectors were determined by calculating the dose rate from a plume at various distances from the plume centerline. Figure 9 gives the dose rates at 1600 m for three different stability classes (A, C, and F) as a function of distance from the plume centerline for a ground level release of 1 Ci/s. The curves given in Figure 9 describe one-half of the plume shape; from the centerline to one edge. The plume shapes and dose rates were calculated for 80 keV gamma rays (^{133} Xe) using the equation and input factors given in Section 2.2.

The number of detectors required for two adjacent detectors to give responses within factors of 2, 3, 5, and 10 of each other was determined based on the plume shape (i.e., the width of the plume). For the plume shape corresponding to stability class C (Fig. 9), the lateral distance from the plume centerline which gives a signal equal to one-half of the maximum was determined to be ~7.8 degrees. Dividing a 360 degree circle by this value gives a value of 46, which is the number of detectors required for two adjacent detectors to give a response within a factor of two of each other. The same process was used to establish the number of detectors required to give readings within factors of 3, 5, and 10 of each other for each stability class. In all cases, it was assumed that the plume centerline was directly over one detector. This is the worst case situation.

Figure 10 shows the number of detectors at 1600 m required to give responses agreeing within 200%, 300%, and 500% as a function of stability class. These results are for straight line meterology, a release height of 100 m, and an average gamma ray energy of 80 keV. For class F weather (the worst case) about 85 detectors are required for two adjacent detectors to give signals within a factor of two of each other. For a ground-level release, approximately 100 detectors would be required for a factor of two agreement. Even for class B weather and a release height of 100 m, about 36 detectors would be required for agreement within a factor of two.

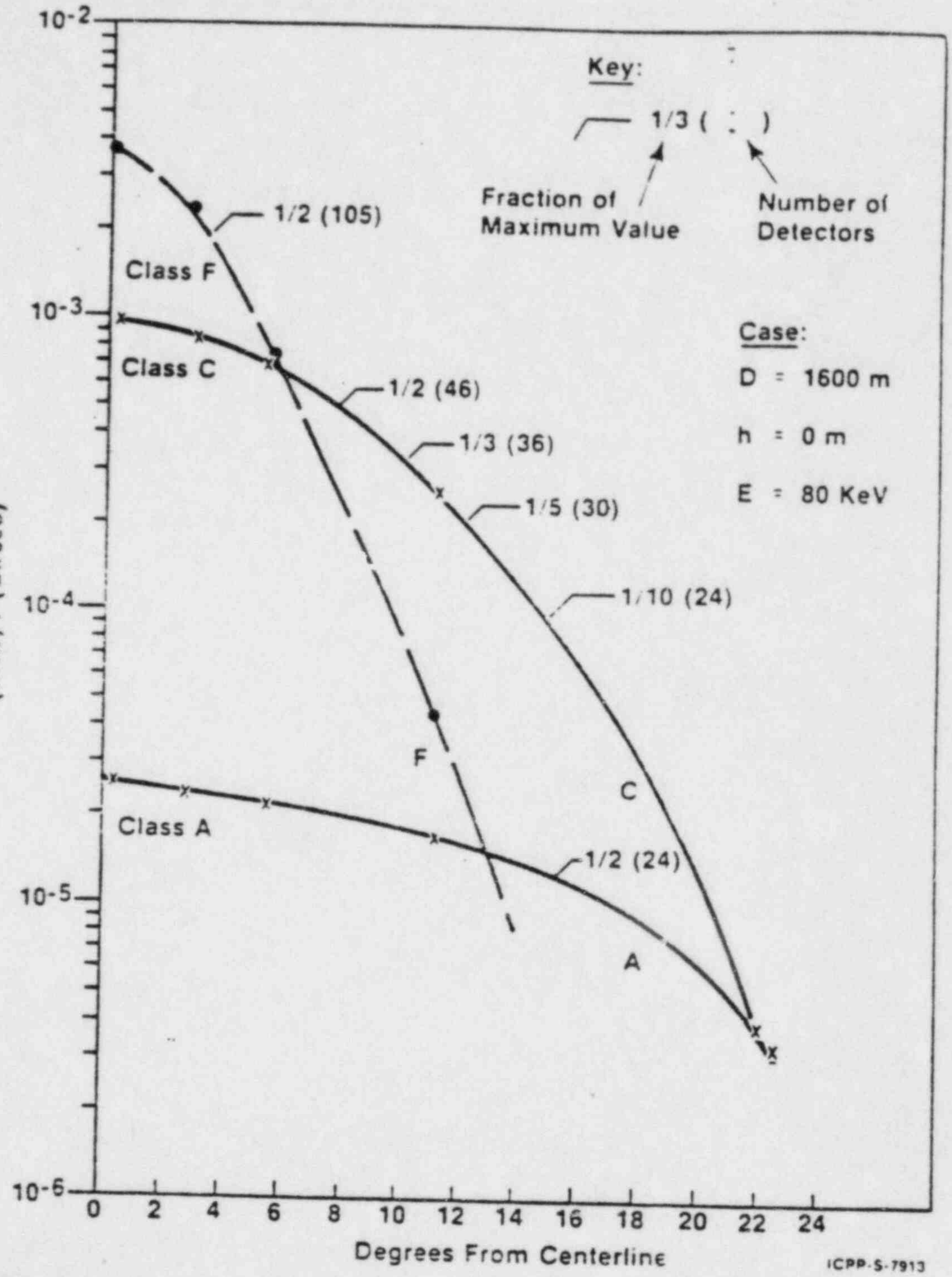

Figure 9. Plume Shape Analysis for Determining Detector Requirements

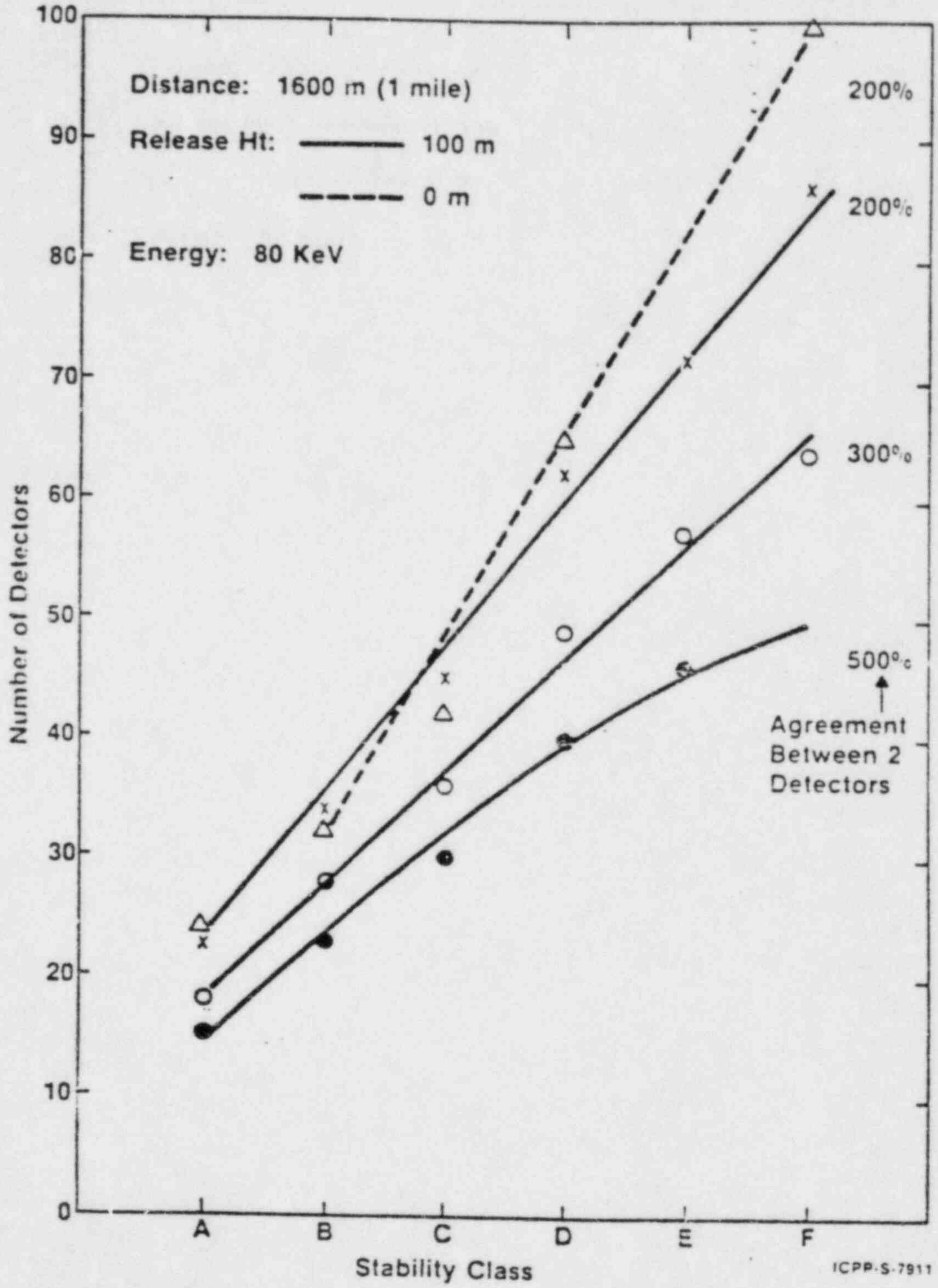

Figure 10. Number of Detectors Required at 1600 m to give Response within 200, 300, and 500%

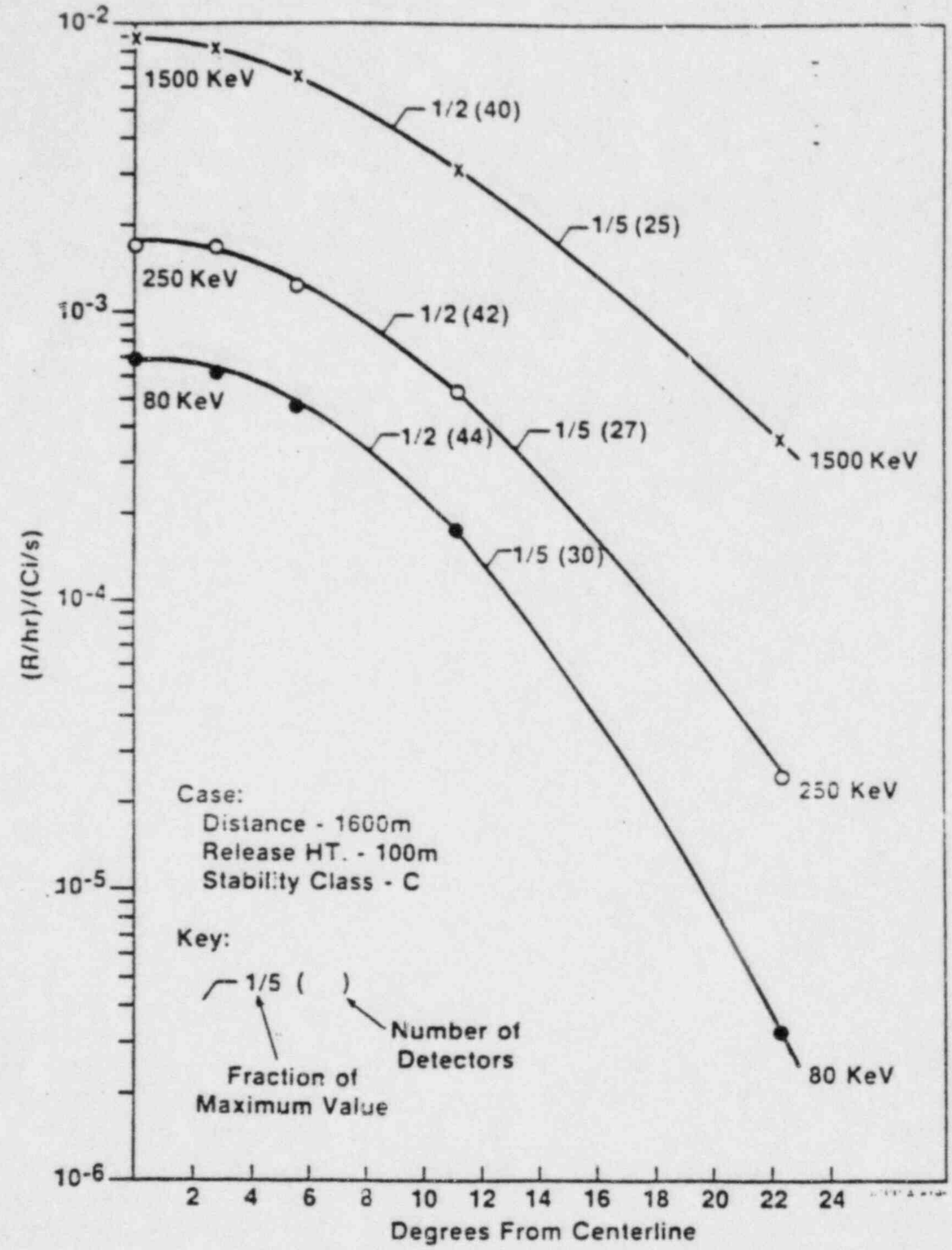

Figure 11. Detector Requirements as a Function of Cloud Dose Gamma Ray Energy

Table V. DETECTOR REQUIREMENTS

DISTANCE, m	RELEASE HEIGHT, m	AGREEMENT BETWEEN TWO DETECTORS	A	B	C	D	E	F
			WEATHER CLASS — NUMBER OF DETECTORS					
800	0	x 2	23	30	40	58	69	90
		x 5	15	19	25	36	42	51
		x 10	--	16	20	28	33	38
800	100	x 2	25	30	39	43	46	58
		x 5	16	19	24	26	29	30
		x 10	--	16	19	21	22	24
1600	0	x 2	24	32	42	65	--	100
1600	100	x 2	23	34	45	62	72	86
		x 3	18	28	36	49	57	[illegible]
		x 5	15	23	30	40	46	50
3200	0	x 2	--	44	55	69	103	138
		x 5	--	34	40	46	65	80
		x 10	--	32	36	40	55	66

Table V gives additional data for distances ranging from 800 m to 3200 m. As expected, the number of required stations increases with distance. These data also show the dependence on release height, with the worst case being a ground level release.

The effect of more energetic gamma rays from shorter-lived noble gas nuclides on the number of detector requirements has been evaluated. Plume shape and detector requirement calculations similar to those shown in Figure 9, page 26, were made for three different gamma ray energies: 80keV, 250keV, and 1500keV. The conditions assumed were class C weather stability, and a release height of 100m. The results given in Figure 11 show little change in the overall plume shape with respect to gamma ray energy and hence, little significant difference in the number of detectors required to give responses within factors of two or five of each other.

Based on the results of these calculations, it is quite evident that offsite real-time monitoring systems consisting of 16 or even 32 units may not provide information on centerline dose values and plume location because of the limited number of detectors. In some cases, especially for extremely narrow plumes (stability classes E and F), the plume might pass between two detectors and go undetected, or if detected, the magnitude of the dose associated with the plume could be greatly underestimated unless it passed directly over one of the sparsely placed detectors. Conversely, in our opinion, the installation of a 100 unit detector system is not practical, feasible or cost effective.

3.2 Building Shine and Background

Some consideration has been given to the installation of real-time monitoring systems within the confines of the site boundary; distances of 500-800 m are typical. In the event of an accident, it is quite probable that the background resulting from building shine could result in a significant signal to near-by detectors. To evaluate the magnitude of this component we calculated the dose to a receptor as a function of distance for the following condition:

1. 100% of the Krypton and Xenon isotopes and 50% of the iodine isotopes were released from the core.

2. Of these amounts 1% of each leaked to the reactor building.

3. The following reactor building contents (based on WASH-1400[14] for a 12 hr decay period).

^{87}Kr	2.4 Ci	^{131}I	1.2×10^5 Ci
^{88}Kr	1×10^4 Ci	^{132}I	4.8×10^3 Ci
^{133}Xe	4.8×10^5 Ci	^{133}I	1.7×10^5 Ci
^{135}Xe	4.1×10^4 Ci	^{134}I	22 Ci
		^{135}I	6.5×10^4 Ci

4. No significant shielding (BWR).

5. Building volume = 5×10^4 m^3.

Using the building contents given above, the dose rate from this source was calculated for various distances from the building using the code ISOSHLD-II[15]. The results for the rare gas and iodine components are given separately in Figure 12. These data indicate a significant increase in the normal background level (0.01 mR/hr) due to the contents of the building, especially at distances of less than 1000 m.

The question of shielding the detectors from this source has not, in our opinion been adequately resolved. Complete shielding of the detector from this source would only negate the signal from a plume. The value of partial shielding in the direction of the building shine is questionable considering the scattered radiation from the building.

To evaluate the impact of the building shine on a signal from a passing plume we have included in Figure 12 the contribution from a plume of ^{133}Xe based on the building contents given above and a leak rate of 1%/day, giving a source term of 0.055 Ci/s. Also assumed was class E weather, a wind speed of 1 m/s, a release height of 100m, and that the bulk of the iodine was retained in the reactor building or trapped by the filter system and therefore had no significant contribution to the plume dose.

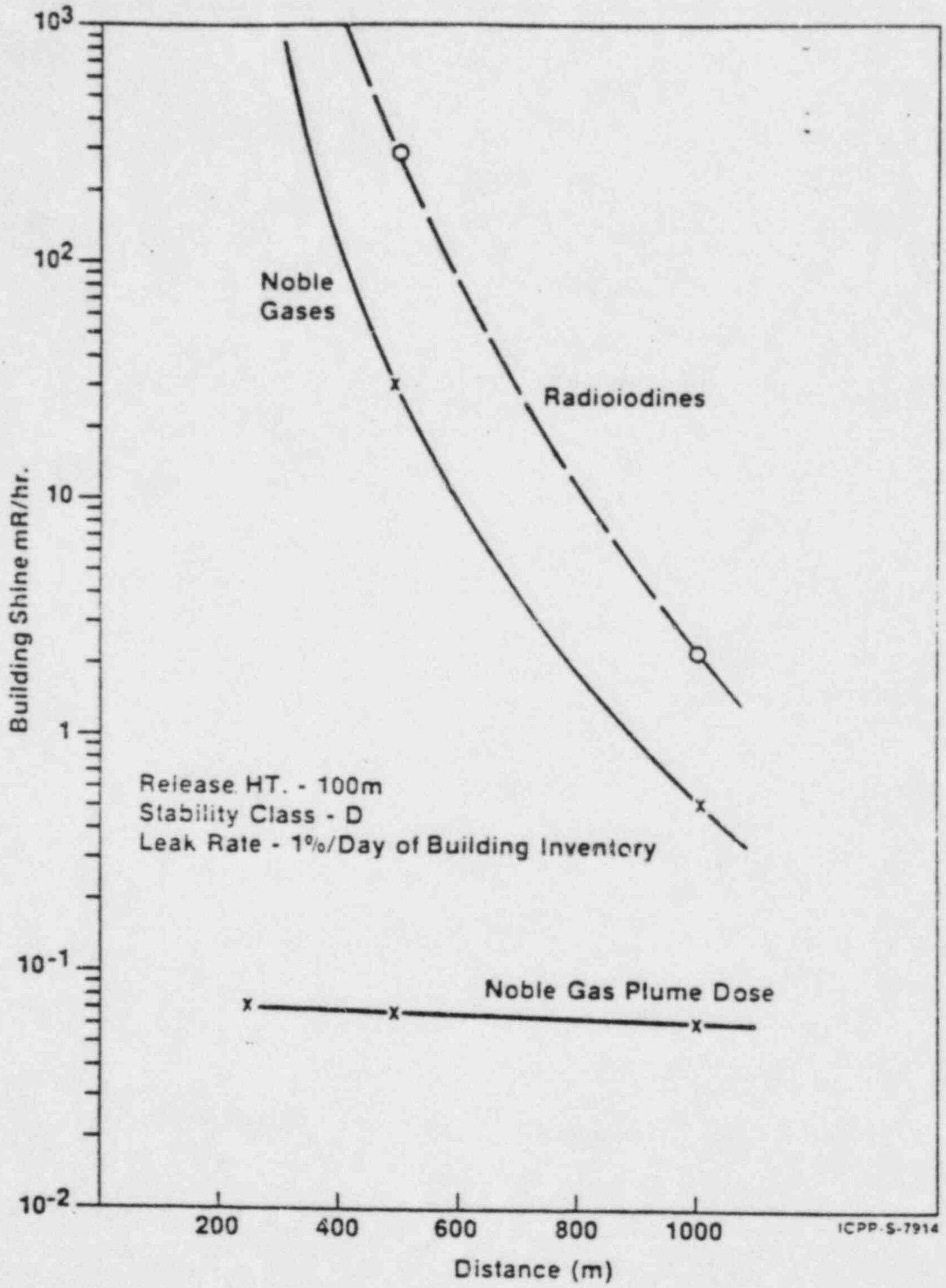

Figure 12. Effect of Building Shine on Detector Response

The results of this calculation clearly show the significance of the building shine factor relative to the plume dose. For the accident case where significant quantities of the volatile radioactive products are in the reactor building, little or no information regarding the plume dose could be obtained from detectors located close to the reactor building.

4.0 INSTRUMENTATION REQUIREMENTS, AVAILABILITY AND SYSTEM COSTS

The basic components of an offsite real-time monitioring system are shown in Figure 13. Also identified, are the major cost areas to be considered in establishing an offsite, real-time monitoring system. Currently, virtually all of the existing real-time monitoring systems which have been installed are for the purpose of monitoring routine releases rather than for use in emergency situations. Although the immediate use is different, the equipment and costs should be similar. Because many of these systems have only recently been installed or are in the installation stage, little information or cost figures are available in the open literature.

To obtain the information necessary to establish an estimate of the costs involved in the installation of a system for use in an emergency situation, several utility stations and state agencies were contacted. These conversations ranged from rather open discussions to quite guarded comments, and in some cases, a reluctance to quote cost values. Also vendors of potentially useful instrumentation were contacted.

A review of the instrumentation requirements and availability of real-time monitoring systems is given in Section 4.1. Section 4.2 gives a review of total system cost and an estimate of the installation costs based on information gathered for existing or planned systems.

4.1 Instrument Description and Requirements

The basic requirements for an offsite, real-time monitoring system are listed below and shown diagramatically in Figure 13.

4.1.1 Field Stations. Field Stations will consist of radiation detecting devices and associated electronics. The stations would preferrably have the capability of signal averaging and onsite readout. The radiation detection system should be capable of measuring dose rates

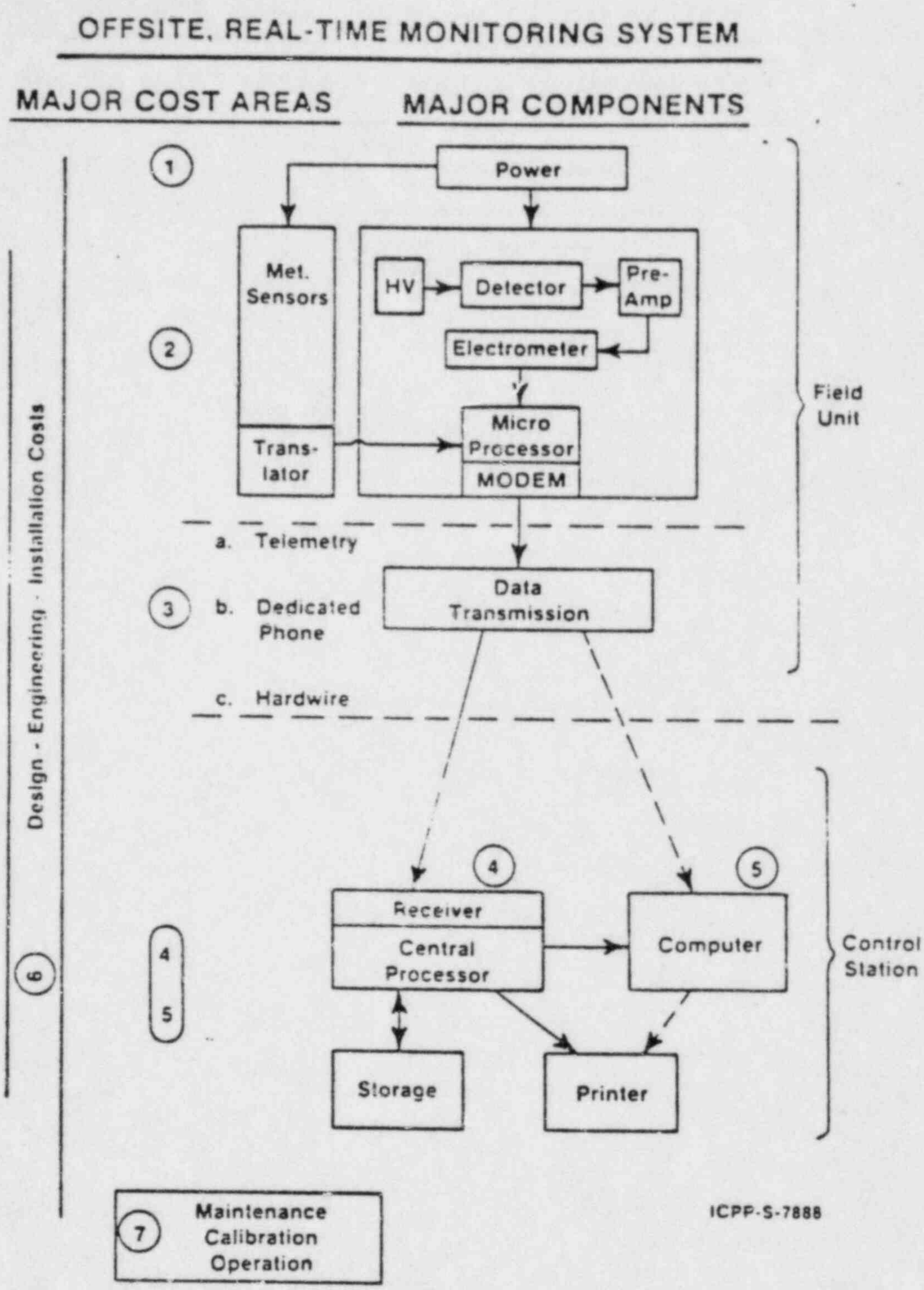

Figure 13. Schematic of Offsite Monitoring System Basic Components

from 1μR/hr to 10 R/hr with reasonable accuracy (± 10%) and respond in a relatively flat manner to photons of 50 to 3000 keV. The detector(s) should be weather proof and the associated electronics enclosure maintained at suitable operating conditions. This may require heating or cooling depending on site conditions. For the winter of 1981-2, the heating requirement could be significant. A provision for backup power should be made.

Additional instrumentation, such as meteorological sensors and iodine sampling devices may be added to the field stations. This additional instrumentation may provide useful data but the cost per field station will be increased.

4.1.2 <u>Data Transmission</u>. Three practical methods exist for transmitting data from the field stations to the central processing unit and commands from the central processing unit to the field stations. These include direct hard wire connections, dedicated telephone lines and radiotelemetry. The choice for specific site will depend on economic and environmental factors. The selected system must be capable of:

1. Bidirectional operation,
2. Error detection and correction,
3. A useful transmission rate, and
4. A transmission structure compatible with the accumulated data.

Direct wire connections often provide the most reliable connections. However it may be impractical to use hardwire connections over water or at distances greater than one mile.

Telephone systems using voice grade lines for data and command transmission can be installed by and then leased from telephone companies. Bidirectional transmission is preferred, although half-duplex is adequate.

Several commercial vendors including those of real-time environmental monitoring systems supply compatible telemetry systems. Line of sight transmission of up to one mile can be performed using an FM system.

As with other field stations electronics, transmitters and encoders must be protected from the environment and, at colder sites, heated.

4.1.3 Central Processing Unit (CPU). The CPU performs the acquisition, reduction and storage of data describing radiation dose rate conditions existing at each field station. The CPU also performs the following functions: 1) diagnostic testing of these data to provide dose rate and meteorological condition time average values for each station, 2) the comparison of radiation data to alarm points, 3) compilation of historical data files, and 4) polls the field stations for radiation dose rate levels at requested intervals. The CPU also should have an interface for transferring the acquired data to an external computer for plume analysis, characterizations, and the ultimate prediction of downwind dose values. Hardware required for these tasks include:

1. Data receiver and decoder
2. Microprocessor,
3. Data storage device,
4. Printer,
5. Command entry device, and
6. Back-up power supply.

4.2 Instrument Availability

The capital costs of obtaining and installing an emergency monitoring system were estimated from costs of existing routine monitoring systems. To prepare capital cost estimates for an emergency monitoring system, three vendors of routine monitoring systems (GCA Corporation, Harshaw Chemical Company and Reuter-Stokes) were contacted. None of these vendors offer systems which are capable of simultaneously monitoring routine radiation releases and meteorological conditions, transmitting this information to a CPU which subsequently models the release and provides dose rate characteristics. The existing systems provide real time remote location dose rate data which is transmitted to a CPU and converted to information such as count or dose rate averages, anomalies and alarm points. All three vendors offer a CPU which can be interfaced with an external computer for characterizing and predicting dose rates. It is interesting to note that the only external computer that each of the three vendors recommends interfacing to their CPU is the Digital Equipment Corporations PDP-11/34. Details of the features, capabilities and price for each of the three systems are discussed below and summarized in Table XI.

GCA Corporation

The GCA Corporation has installed several of their "Guardian" systems at power stations in the United Kingdom for the purpose of providing routine real-time environmental monitoring. The "Guardian" system employes two GM detectors (low range, 10^{-6} - 10^{-2} R/hr, and high range 10^{-3} - 10 R/hr) at each field station for radiation detection. In addition, a "Maypac" particulate and iodine filter system with constant air pump can also be placed at each field station. Data transmission from the field stations to the central processing unit is usually performed by VHF radiotelemetry, but other methods are possible. The "Guardian" CPU provides immediate hard copy and visual display of current field station readings, system diagnostics, and data logging. Although the "Guardian" system has been marketed in the USA since 1981 it has not been installed and operated at any power station in this country. Installation costs and operational characteristics of this system can be obtained by contacting power station personnel in the U. K.

The Harshaw Chemical Company

The Harshaw TASC-4 systems may be used for routine real time environmental radiation monitoring. This system uses two scintillation detectors per field station to give monitoring capabilities over seven decades of signal. Data transmission from the field stations to the CPU is by dedicated hard wire systems because generally the units are used inside of buildings where the distances are short. An advantage of the Harshaw TASC-4 system is that all field station electronics, except the preamplifier, can be placed in the CPU thus minimizing the effects of weather on the system, lowering the potential for tampering at the field stations, and centralizing much of the maintenance. Components of the CPUs of these systems also include counter-timers, printer, and computer interface modules. To date none of these systems have been installed to function as routine real time monitoring devices at distances being considered in this study.

Reuter-Stokes

The Reuter-Stokes Sentri-1011 system, designed specifically for real time routine radiation monitoring, has been installed at several nuclear power stations in the USA. The field stations of the Sentri 1011 systems are equipped with high range (10^{-3} - 10 R/hr) and low range (10^{-6} - 10^{-2} R/hr) pressurized ion chamber detectors and associated instrumentation. Reuter-Stokes is presently developing a single detector to provide accurate monitoring over seven decades of signal which should result in a reduction of a capital cost and installation. Data transmission from the field station to the CPU of the Sentri-1011 system can be accomplished by radiotelemetry, dedicated telephone lines, or hard wire. The Sentri-1011 CPU performs field station data reduction, system diagnostics, and data logging. Historical information can be obtained in hard copy and the unit contains an interface port for an external computer.

Reuter-Stokes is the only vendor which offers a compatible meteorological accessory package for their field stations. This package, the "3-D Wind System," is marketed by Climatronics and is described in Table VII.

4.3 System Costs

Several commercial power reactor stations and state radiological monitoring agencies were contacted relative to obtaining cost information regarding the purchase and installation of offsite, real-time monitoring systems. Although the systems which have or are being installed are for the purpose of monitoring routine releases, the basic instrumentation and cost data should be similar for an emergency montoring system. In some cases, detailed cost information was not available because the systems were still being installed or existing systems were being modified or expanded. Information regarding date of installation, number of fixed stations, distance from the source, and type of data transmission is given in Table VIII. All of these systems are using the Reuter Stokes Sentry-1011 monitoring system.

The cost factors for these systems are quite variable because of varying degrees of instrumentation complexity and whether a subcontractor was involved in the design, purchase, and installation of the system. The range in the costs per monitoring unit is approximately from $20,000 to $40,000/unit. In general, the higher priced systems included a meteorological sensing component and/or additional subcontractor costs. For purposes of this survey an average cost of about $30,000 per unit appears reasonable. This value includes the costs of all monitoring and data transmission instrumentation. The cost of a central data processing unit and a computer for extended data handling and reducing capibilities is variable depending on whether dedicated or existing hardware is used for this purpose.

A much more ambiguous cost is that regarding the installation of the field units. If the monitoring unit is installed on existing supports (power transmission poles) and the power source is readily available, the installation costs may only amount to a few thousand dollars ($3,000 - 5,000) per unit. Conversely, if special supports are required

or if the units are installed over water, the average station costs could increase five fold ($25,000/unit). Additional cost would also be incurred if special power lines and installation are required. For example, use of uninterrupted power from the Auxiliary Building could add several hundred thousand dollars to the overall costs.

Other costs which must be considered but are difficult to quantify include design and engineering, purchase of land if necessary, depreciation, routine maintenance, dedicated telephone line leasing fees, and operating cost. The last item could be significant if a group of dedicated operators (meteorologists) were assigned to operate the system and evaluate the data.

Based on the data currently available, the following range of cost figures are given for a 16 unit station at a distance of 2 miles.

	Range of Costs ($000)
1. Instrumentation $20-40K/unit	400 - 640
2. Data Collection and processing equip.	40 - 110
3. Installation $5-25K/unit	80 - 400
4. Design and Engineering	50 - 200
5. Contingency	100 - 200
	$670 - $1,610

The lower cost figure does not insure uniform placement of the monitoring units because existing support poles are considered for use. Thus, it is quite probable that a release could go undetected if it consisted of a compact plume (stability class E or F). Considering that we are only referencing a 16 unit system this same comment could apply even if the monitoring units were uniformly spaced on a ring. Therefore, one could raise a question regarding the technological validity of the entire concept. To increase the number of stations to give highly reliable measurements would result in increasing the overall cost of a system by several million dollars.

TABLE VI
VENDOR DATA FOR REAL-TIME MONITORING SYSTEMS

	Field Station Detector Electronics	Data Transmission	Central Processing Unit (CPU)
Harshaw Chemical Co. TASC-11			
Features	Two weatherproofed CaF_2 (Eu) Scintillation detectors. Wired power backup.	Hard wire.	All field station electronics except preamplifier are at CPU.
Capabilities	Two detectors span seven decades of signal (1μR/hr - 10 R/hr). and withstand temperature variations of 15°C/hr.	Hard wire use demonstrated up to one mile.	Field station electronics at CPU record and print out monitoring data. External computer required for other data reductions and displays.
1981 Prices	$7K per station including electronics.	Included in field station price.	$4.2K for CPU consisting of computer interface, data recorders, counter and timer.

TABLE VI (Cont'd)
VENDOR DATA FOR REAL-TIME MONITORING SYSTEMS

	Field Station Detector Electronics	Data Transmission	Central Processing Unit (CPU)
GCA Corporation "Guardian"			
Features	Two weatherproofed GM detectors, digital display, detector range changer, solar powered battery backup and "Maypac" particulate and iodine filters. Automatic detector range changer.	RF telemetry, dedicated telephone, hard wire.	CPU has teletype printer, visual data display, data storage, alarm and status system, and external computer interface.
Capabilities	Two detectors span seven decades of signal (1μR/hr - 10 R/hr) with ± 5% accuracy at 10μR/hr. Energy response between 60 KeV and 3 MeV is ± 20% Temperature operating range -10°C to +60°C.	Hard wire or dedicated phone line possible.	Processes data from up to 31 field stations. Field stations scanned at 5 second intervals in system alarm mode, 5 minute intervals in in non-alarm mode.
1981 Prices	\$15K per station with telemetry \$10K per station with hard wire or telephone.	Included in station cost	\$50K

TABLE VI (Cont'd)
VENDOR DATA FOR REAL-TIME MONITORING SYSTEMS

	Field Station Detector Electronics	Data Transmission	Central Processing Unit (CPU)
Reuter - Stokes Sentry 1011			
Features	Two weatherproofed pressurized ion chamber detectors. Digital display, strip chart recorder, 8-hour battery power backup, serial readout and automatic detector range charger.	Hard wire, dedicated telephone, or RF telemetry.	Basic CPU processes input from 16 field stations, reduces and stores exposure rate data. CPU also has alarm and system diagnostics, and external computer interface.
Capabilities	Two detectors span seven decades of signal (1μR/hr - 10 R/hr) with ± 5% accuracy at low levels. Temperature operating range is $-25^{o}C$ to $+ 55^{o}C$.		Basic CPU can be upgraded to process input from up to 48 field stations. Scan of field stations can be done at 5 second to 5 minute intervals.
1981 Prices	$11.3K per station (detectors cost $3K a piece)	$3.5K per station for telemetry. Hard wire about $2K per station at 0.5 miles.	$39K to process input from 16 stations. $70K to process input from 48 stations.

TABLE VII

Climatronics "3-D" Metorological Montoring System

	Field Station Electronics	Data Transmission	Central Processing Unit (CPU)
Features	Sensor package inputs to field computer to determine θ and Φ Can use dedicated telemetry for radiation detection electronics for transmission. Ten meter tower, sensor heater and electronics housing required.	Dedicated 2-way telemetry system recommended for real-time monitoring but telephone and hard wire is possible.	Field computer output transmitted directly to modeling system to determine stability class.
Capabilities	Solar power, temperature dew point sensors also available.	Two-way RF can relay commands to station such as time averages and scan times.	Station sensors used with doppler monitor for forecasting would give more information for modeling.
Cost[a]	$10K/station for the above features and capabilities.	$3.5K/Station for 2-way RF telemetry	$3K for RF central processing unit

[a]1981 purchase prices

TABLE VIII
REAL-TIME INSTALLED MONITORING SYSTEMS

Faciltity (Owner)	Installation Date	Number of Monitoring Units	Distance from Sources (miles)	Data Transmission
Diablo Canyon[a] (PG & E)	1981	12	5-10	Phone
La Salle (Comm. Ed)	1980	8[b]	2	Phone
Berwick (Penn. P & L)	1980	2[c]	15-26	None
Virgil C. Summer[a] (SC G & E)	1981	8	0.5	Hardwire
Three-Mile Is. (Metro. Ed)	1980	12	0.1-4	Phone
Indian Pt. -2[a] (Con. Ed.)	1980	16	0.5-2.5	Telemetry
San Onofre (So. Cal. Ed.)	1981	9[d]	0.6	Phone

a) Field stations include meteorological accessories
b) When completed system will have 16 field units
c) Complete system will have 7 field units
d) Complete system will have two rings of 9 stations each. One at 1000m and the other at 2000m.

5.0 MATRIX EVALUATION

One of the primary objectives of this program is to evaluate the concept and usefulness of an offsite real-time monitoring system in the light of a matrix array and associated parameters. The matrix and its three major components, accuracy, cost, and detector sensitivity were presented in Section 1. Based on the review and studies conducted in the prior sections of this report our evaluation of the matrix is as follows. For ease of reference the matrix array is reproduced on page 51 as Figure 14.

Accuracy - The accuracy level was evaluated based on the uncertainty associated with the quantification of an unmonitored release in the presence of a monitored release. Based on our study we propose eliminating all conditions associated with accuracy values for factors of 2, 5 and 10. In some cases, especially for the case where the unmonitored release is small compared to the monitored release, even the accuracy factor of 50 for the unmonitored release may be a question.

Detector Range - The requirement for detectors sensitive to the measurement of a quantity of radiation equivalent to 0.1 background (1 μR) cannot be justified, especially when the background can fluctuate more than this amount. A similar argument can be made for detector systems having a lower range equivalent to background (10 μR/hr) because the uncertainty in the signal would be large and a reading equivalent to background in an emergency situation would not be significant relative to the initiating protective action in the surrounding areas. One might make a case for the use of detectors having a lower range of 10 μR/hr in establishing site specific diffussion models based

on the monitoring of normal releases. However, if the detectors are placed at a two-mile distance from the plant, the dose rate from normal releases would be so small as to be garbled in the normal background fluctuations. In our opinion, detectors with a lower range of 10 times the background level or 0.1 mR/hr should be adequate for an offsite real-time monitoring system, because readings of less than 0.1 mR/hr are of little significance from a hazard standpoint. This is a point which should be presented as part of the public relations effort of the utility. This conclusion eliminates the two lower levels of the matrix.

Cost Factors - This item is more difficult to assess because of the wide range of values associated with the installation costs. We can, however, make some general comments. If a low cost system is installed with a minimum (8-12) number of stations, there is a high probability of missing a plume, in which case the system has little technological value. To install a minimum system with detectors only near population centers may have appeal from a public relations standpoint but it does not provide the technical data which is necessary to assess the impact of a plume to the rural areas which could be populated by grazing milk cows. Also, if the detectors were not uniformaly spaced near the population centers, false information relative to the intensity of the plume dose could result.

We do not support the installation of a minimum system, which we are associating with a $250,000 cost value, because the technical information obtained from such a system would be of questionable use in a decision making process.

Similar arguments can be made for a $750,000 system; however, at this level each installation would have to be evaluated on an individual basis because of site specific characteristics. Obviously the requirements for a monitoring system in a flat terrain situation is different from one involving water, off-shore and on-shore breezes etc. In some cases, a system constructed for a cost of $750,000 might provide reasonable technical information. Thus, we have decided to leave this area of the matrix open but emphasize the site specific characteristic of the case.

For $2,000,000 one might construct a reasonable system, but in no case would information accurate to a factor of 5 or 10 be obtained. In fact, almost no sum of money would insure obtaining dose values to this level of accuracy.

Based on the above discussion and evaluation, the bulk of the matrix has been eliminated. The remaining areas which we feel identify the potential benefits and associated uncertainties from the installation of a fixed off-site real-time monitoring system are shown in gray in Figure 14. While it is acknowledged that our conclusions are argumentative, we believe they are representative of the current state the of art.

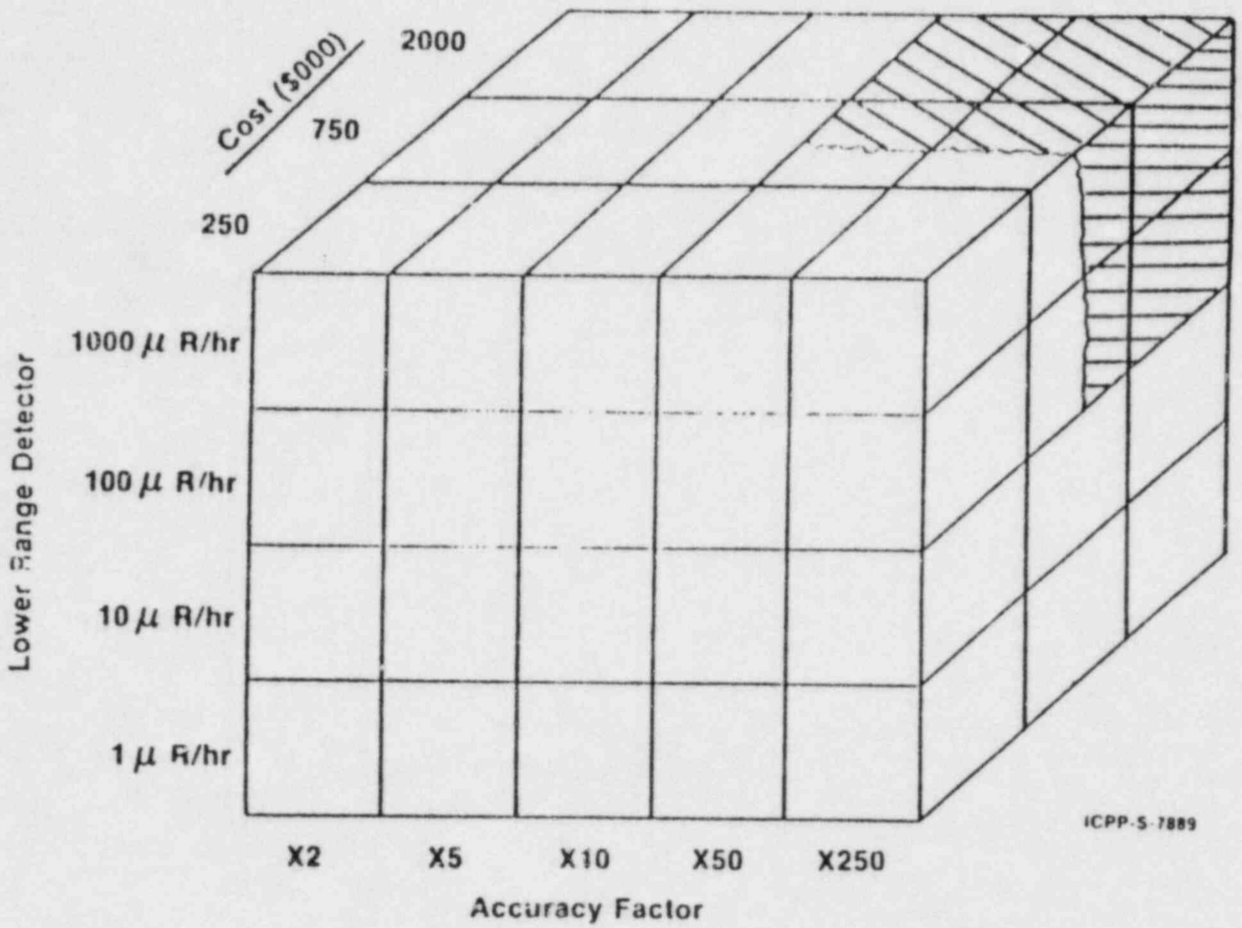

Figure 14. Matrix Parameters

6.0 MINIMUM-COST EMERGENCY SYSTEM

An augmented effort to the general program involved the characterization and evaluation of a specific, minimum cost emergency system with close proximity to the plant. The constraints to be applied to the evaluation of such a system are as follows:

1. Total system cost - not to exceed $500,000,
2. Detector assembly cost - not to exceed $7,000/unit
3. Detector distance - no further than 800 m (0.5 mi),
4. Detector sensitivity - 0.1 mR/hr to 10 R/hr, and
5. Accuracy - within a factor of 10.

Using the cost data presented in Section 4, the following values were used to establish the magnitude of the system which could be installed within the $500,000 constraint.

Fixed Costs

Central Processor (with modeling, 48 station capacity)	$110,000
Design and Engineering	40,000
	$150,000

This leaves a balance of $350,000 which can be allocated to the cost of the detector assembly, data transmission, and installation. The cost per station is estimated as follows:

Dectector Assembly		$ 7,000
Data Transmission/Unit		8,000[a]
Installation/Unit		3-15,000[b]
	Total/Unit	$18-30,000

---

[a] Includes capital cost and installation

[b] highly variable depending on specific location

For this exercise it was assumed that the data transmission would involve a telemetry system because the cost of installing hardwired or dedicated phone systems is highly variable. For example, climatic factors may dictate the burial and/or the use of special material in each of these data transmission systems. The installation costs are based on simple units all installed on flat solid terrain. If uniform placement of the detector assemblies required installation in cooling ponds, rivers, or other bodies of water, the installation costs would increase significantly, perhaps by as much as a factor of five for those units in such a location. Another significant expense item is the power source. If an uninterrupted power supply from the Auxiliary Building is used the cost per station would be significantly more, especially if underground or underwater lines were used.

Based on an after fixed-cost balance of $350,000 which can be allocated to the detector units, and a range of average station costs of $18,000 - $30,000, from 12 to 20 detector units could be installed depending on the actual placement of the units.

The 12 unit system would insure equal placement of the units regardless of the location. The 20 unit system could have voids in the monitoring grid and be operated with normal power sources.

The estimate appears reasonable based on information obtained from two utilities which provided cost information for a comparable system. One station which recently completed installation of an 8 unit system at a distance of 800 m (0.5 mi) quoted a cost of about $435,000 for the purchase and installation of the package. In this case, each unit also included a meteorology station and the output from the unit was hard-wired to the control station and coupled to an existing HP-1000 data processer. Thus, the total cost per unit is approximately $54,000.

The overall cost would increase if a dedicated CPU were used and probably decrease if some other form of data transmission were used. The cost per unit would also decreasing if meteorology sensors were not installed with each unit, but the validity of any down-wind projection would also decrease.

A second utility while not providing complete capital cost data did provide sufficient information to estimate the cost for a ring of nine units at a distance of 1000 m. The central processing unit for this system has not been purchased. However, the purchase cost of the nine field stations was about $135,000, or about $15,000 per station. For the nine unit system using a dedicated phone system for data transmission, the installation cost per unit was quoted at about $23,000 per unit or about $200,000 for the system. This is somewhat higher than our estimate but gives some idea of the costs involved just for installation. Assuming fixed costs of $150,000 for design, engineering, and a central data processer, about $135,000 for instrumentation and $200,000 for installation gives a sum within the $500,000 constraint. The unit cost for the nine detector system is about $55,000, which is similar to the first system discussed.

To estimate the credibility of the data which could be expected from an 8 to 20 unit system we first considered the data given in Table V. Based on these data, a minimum of ~90 equally spaced stations would be required for two adjacent units to give a reading within a factor of 2 of each other when the release was at ground level

and the stability class was F. For two units to agree within a factor of 10 would require a system of 35-40 units. About 30 detectors would be required for more common class D weather. These numbers are based on the assumption that the centerline of the plume passes directly over one of the stations. This is a highly unprobable event. The passage of a plume between two detectors would give a response which underestimates the true magnitude of the release.

A second factor which must be considered for a 500-800 m system, is the effect of the building shine factor, especially for a BWR. For the case given in Figure 12, the plume dose at 800m for a leak rate of 1% per day of the building noble gas inventory is considerably less than the building shine background. The effect of building shine will be much less for a PWR.

The effect of building wake and dispersion of the flow regime by other buildings (other than the reactor building) is a third factor which should be considered. This effect could significantly alter the measurement of the true dose from the plume.

While a close-in detector system might in some instances provide some information in an emergency situation, the ability to extrapolate and project the information to give concentration or dose values at some extended downwind distance (5-10 mi) is highly questionable. This could only be done with a reasonable degree of confidence if site specific modeling and additional downwind meteorological data were available.

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APPENDIX - A

BRIEF SUMMARY OF EXPERIMENTAL RESULTS TO
COMPARE MEASURED AND PREDICTED GROUND LEVEL CONCENTRATION VALUES

A.1 ^{85}Kr Experiment at Savannah River Plant[9]

In this experiment, the release of ^{85}Kr from the Savannah River Plant chemical separations facility was monitored for over a year at six sites within 10 km of the release points. Using the Gaussian plume model for a continuous source, the ratio of the predicted concentration to the measured concentration was determined. The dispersion parameters were those based on the ideal case of flat terrain, short distance, and steady meteorological conditions.

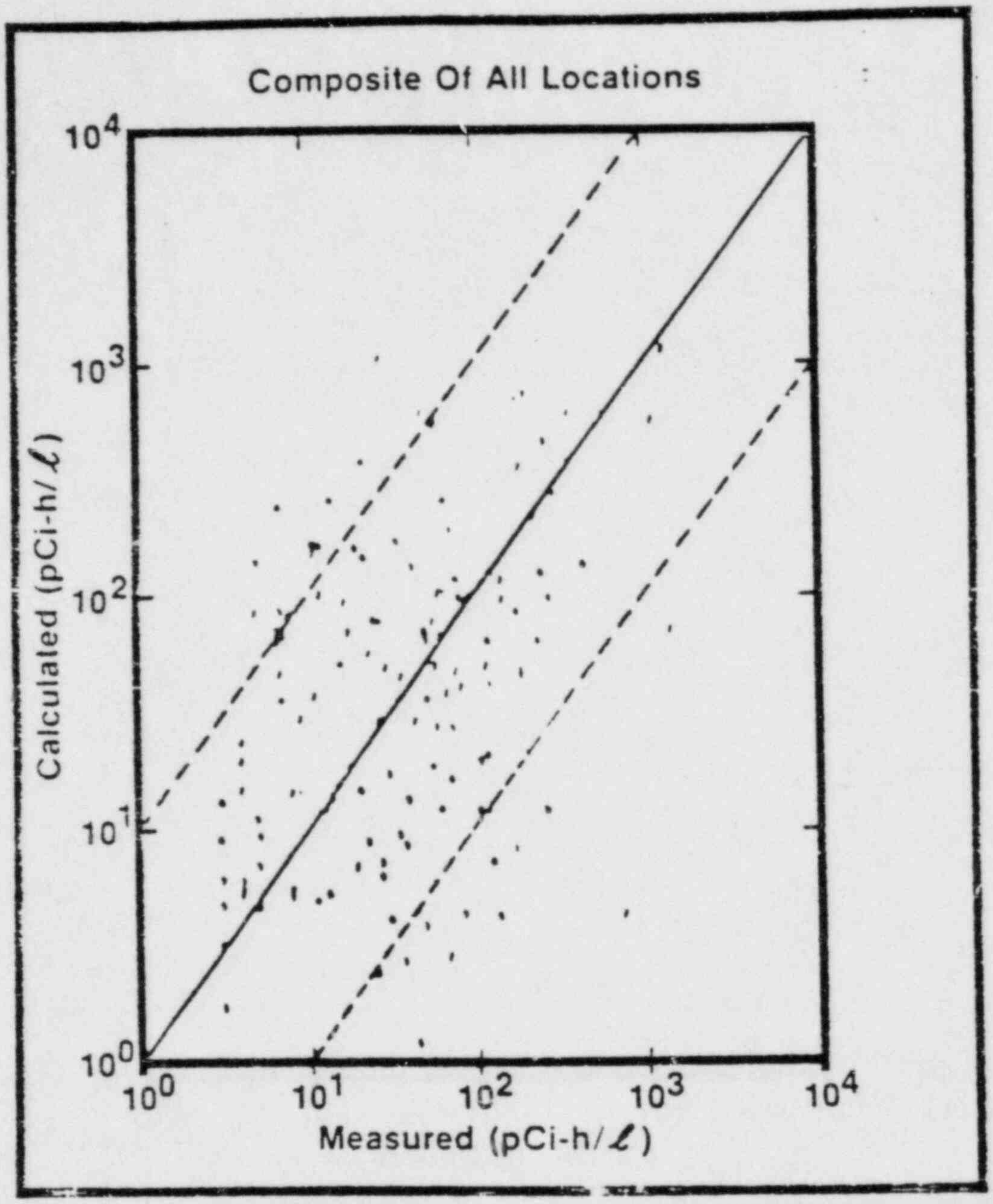
The general results showed that the annual average concentrations were over-predicted by a factor of 2 to 4 compared to the measured values. For the short-term (10 hours), the predicted values were within about a factor of 10, and in many cases, particularly in calm or stable conditions, measurable concentrations were predicted when none were observed. The results of the short-term data are shown in Figure A-1 from Reference 9.

A.2 ORNL Assessment of Hanford Experiment[10]

As part of a DOE sponsored program associated with the Breeder Reactor Program, ORNL is evaluating experimental data obtained from an experiment conducted at Hanford in which zinc sulfide fluorescent particles were released from a height of 111 m over relatively smooth terrain. Crosswind-integrated ground-level air concentration measurements were compared with predicted values using a Gaussian plume atmospheric dispersion model. Of interest was the use of three different sets of measurements to calculate the atmospheric stability class.

a. The vertical temperature difference between 10 and 122 m above ground-level,

b. The standard deviation of the wind direction measure at a height of 122 m, and



ICPP-S-7924

Figure A-1. Measured to Predicted ^{85}Kr Concentrations (ref. 9)

c. A combination of a and b.

For the Hanford data, methods a and b, with one exception, indicate Pasquill stability classes E or F, while method c always indicates class D.

In this study ORNL compared the results obtained as a function of the dispersion factor, σ_z, based on five different sets of diffusion models. Basically, these include those data sets previously discussed and reviewed by Brenk[8] (Pasquill, St. Louis, Briggs' Rural, Brookhaven, and Julich-100 m). Separate comparisions were made between measured and predicted concentration values using each of the five sets of σ_z values and three stability class determinations. A summary of the observed and predicted concentrations values is given in Table A-1.

These data (Table A-1) show that the predicted values differ from the measured values by a factor of 5 to 10 more than 50% of the time and that the predicted value may be more or less than the measured value depending on the dispersion system used and the associated dispersion factors. About 40% of the time the difference between the predicted and observed values can be a factor of 10 or greater; again in either direction.

These data tend to support our initial comments regarding uncertainties associated with the use of the standard Pasquill factors and the need to develop site specific data.

A.3 Excerpts from a Workshop on the Evaluation of Models Used for Environmental Assessment of Radionuclide Releases[11]

The working group suggested some tentative accuracy statements on the estimation of airborne concentrations. These statements are largely based on scientific judgement; there are not enough data upon which to base a reliable statistical estimate. For the ideal situation of a highly instrumented flat-field site from which previous data on meteorology

Table A-1. EVALUATION OF HANFORD EXPERIMENT BY ORNL.

Stability Assignment Method*	% of Observations Exceeding Limits					
	Factor of 5 or Greater		Factor or 10 or Greater			
	(a)	(b)	(a)		(b)	
Pasquill-Gifford	62%	52%	43%	UP**	38%	UP
St. Louis (Smith)	62%	57%	38%	UP	38%	UP
Briggs' rural	43%	48%	29%	UP	33%	UP
Brookhaven	62%	52%	52%	OP	52%	OP
Julich (100 m)	62%	62%	43%	OP	38%	OP

* (a) Stability class based on vertical temperature difference between 10 and 122 m above ground level.

(b) The standard deviation of the wind direction measured at a height of 122 m

** UP - Model underpredicts ground level concentration relative to observed values (i.e $\frac{obs.}{pred.} > 1$ majority of time).

OP - Model overpredicts ground level concentration relative to observed values (i.e $\frac{obs.}{pred.} < 1$ majority of time).

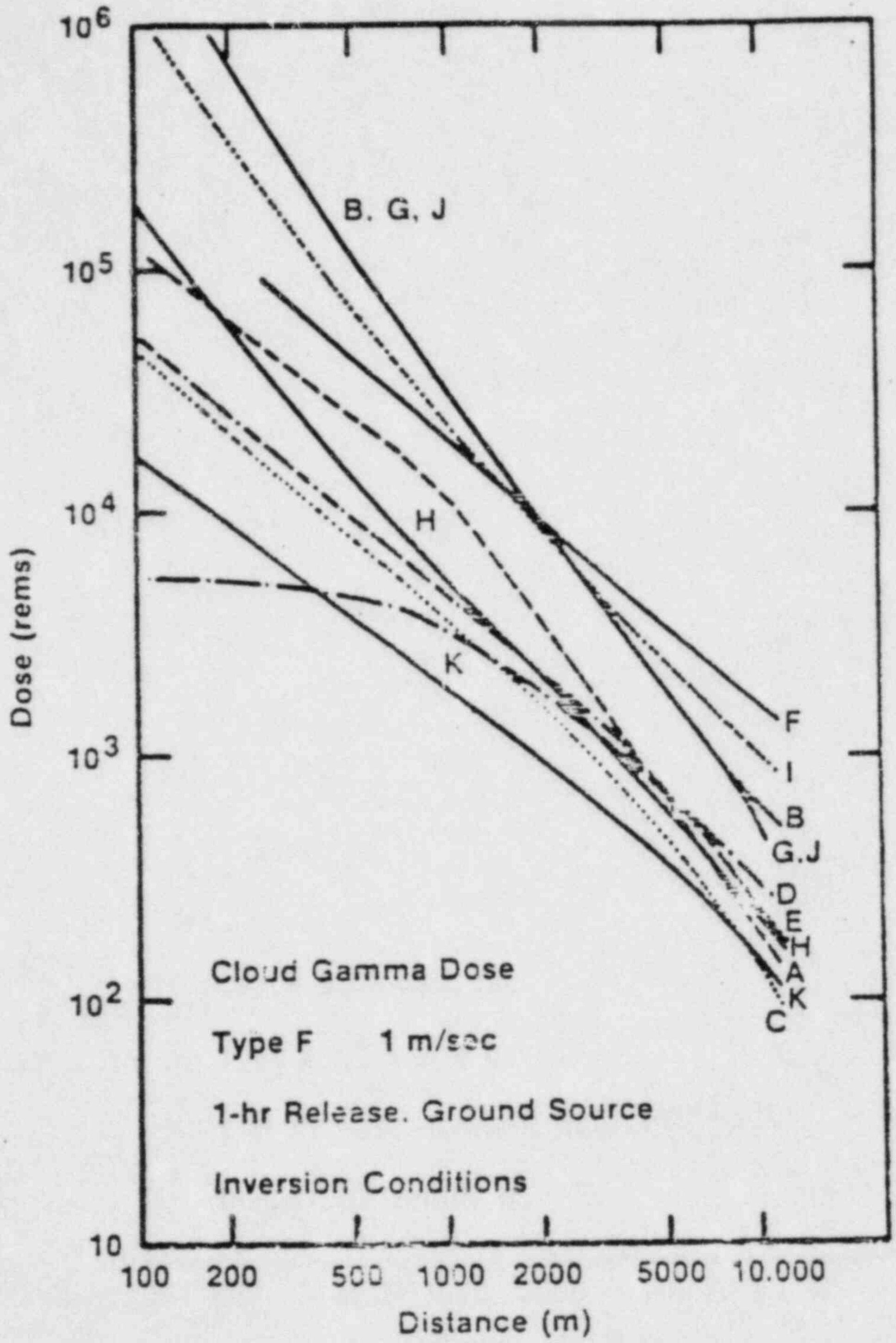
and airborne concentrations were available, it should be possible to estimate to within ±20% the ground-level centerline concentrations from a continuous point source at downwind distances of less than 10 km.

For a specific hour and downwind receptor point, the accuracy is very dependent on the calculation of the exact plume trajectory during a short period. For flat terrain and relatively steady meteorological conditions and distances of 10 km or less, the airborne concentrations for an individual case should be estimated to within about a factor of ±10. For annual average concentrations values, the accuracy estimate is about a factor of 2.

For a complex terrain or meterological situations (e.g., sea breeze regimes) a few experiments have indicated departures from estimates from the Pasquill-Gifford curves of more than a factor of 10. However, there are insufficient data upon which to base even a "scientific judgement" estimate of accuracy.

A.4 Results of a Survey of Programs for Radiological Dose Computations[12]

A standard accident release problem was presented to several nuclear facilities with the request that the cloud gamma dose be calculated as a function of distance. The same input data were used by all participants. The results of the various calculations using identical input are shown in Figures A-2 and A-3. The range in the calculated values is a factor of ~10 at the 1000-3000 m distance. Considering that there are no absolute standards by which to judge the accuracy of the dose calculations, one might question, "how close is the range of values presented by these calculations to the true absolute value?"



ICPP-S-7925

Figure A-2. Comparison of Different Dose Calculation Models, Class F (ref. 12)

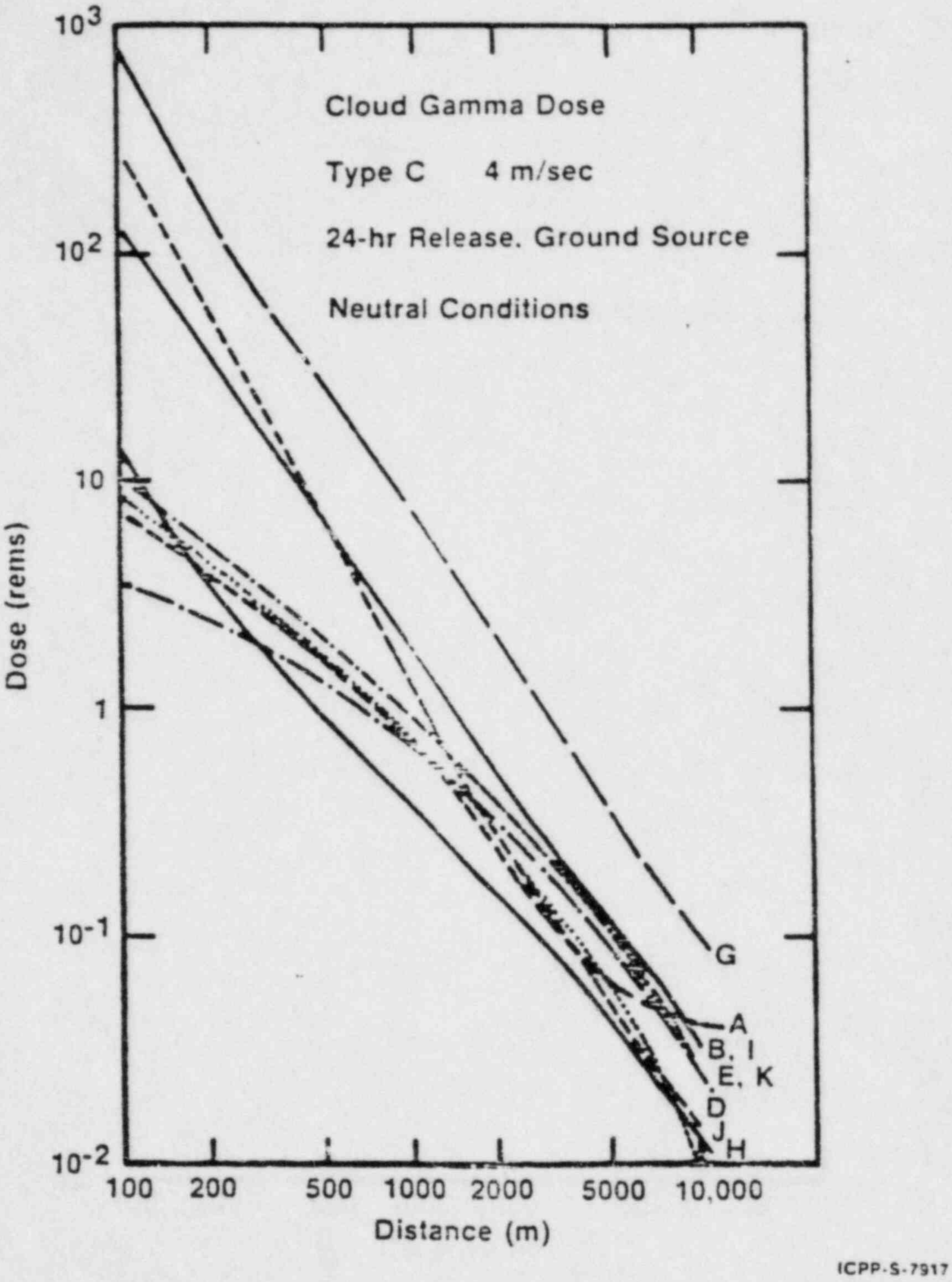


Figure A-3. Comparison of Different Dose Calculation Models, Class C (ref. 12)

APPENDIX E

VALUES FOR σ_y AND σ_z USED IN DOSE CALCULATIONS

TABLE B-1

VALUES FOR σ_y AND σ_z USED IN DOSE CALCULATIONS[a]

Stability Class	Distance							
	500 m		800 m		1600 m		3200 m	
	σ_y	σ_z	σ_y	σ_z	σ_y	σ_z	σ_y	σ_z
A	106	128	164	326	312	1530[b]	586	8294[b]
B	80	53	125	98	239	278	449	920
C	57	35	88	54	167	99	313	176
D	37	19	57	27	108	45	204	71
E	28	14	43	20	81	31	151	47
F	19	9	30	12	56	19	105	27

a Listed data are calculated values based on an equation developed[13] to fit the data given in Reference 3.

b Values greater than 1000 are not realistic because the mixing layer depth (~1000m) can restrict verticle plume growth.

NRC FORM 335 (7-77) U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET**	1. REPORT NUMBER (Assigned by DDC) NUREG/CR-2644 ENICO-1110
4. TITLE AND SUBTITLE (Add Volume No., if appropriate) An Assessment of Offsite, Real-time Dose Measurement Systems for Emergency Situations	2. (Leave blank)
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7. AUTHOR(S) W. J. Maeck, L. G. Hoffman, B. A. Staples, J. H. Keller	5. DATE REPORT COMPLETED MONTH March YEAR 1982
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16. ABSTRACT (200 words or less)

An evaluation is made of the effectiveness of fixed, real-time monitoring systems around nuclear power stations in determining the magnitude of unmonitored releases. The effects of meteorological conditions on the accuracy with which the magnitude of unmonitored releases is determined and the uncertainties inherent in defining these meteorological conditions are discussed. The number and placement of fixed field detectors in a system is discussed, and the data processing equipment required to convert field detector output data into release rate information is described. Cost data relative to the purchase and installation of specific systems are given, as well as the characteristics and information return for a system purchased at an arbitary cost.

17. KEY WORDS AND DOCUMENT ANALYSIS	17a. DESCRIPTORS
Offsite, Real-Time Dose Measurement, Emergency	
17b. IDENTIFIERS/OPEN-ENDED TERMS	

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (This report)	21. NO. OF PAGES
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MC-1

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TPC
TPC
TPC

PROTECTIVE ACTION RECOMMENDATIONS

1.0 PURPOSE

This procedure provides guidelines for determining protective action recommendations to be given to offsite authorities.

2.0 RESPONSIBILITY

The Radiological Control Manager, Radiation Protection Manager or In-plant Radiation Monitoring Technician is responsible for ensuring compliance with this procedure.

3.0 DISCUSSION

3.1 The decision process used in determining a recommended protective action is based upon a number of factors. These factors are: release duration; magnitude of release; plume travel time; evacuation time estimates; dilution factors; shelter factors; dose limits; and dose savings.

3.2 After determining a protective action, the Response Manager/Emergency Director will give approval to such an action before it is recommended to offsite authorities.

3.3 Radiological Control Manager/Radiation Protection Manager or his staff may be available to perform this procedure for different distances used in SP69.Ø22.Ø1 Determination of Offsite Doses. This procedure explains the methodology for determining protective actions for points sequentially.

3.4 Topics covered in this procedure include:

4.0 PRECAUTIONS

Because protective action recommendations could be influenced by factors not considered here, use this procedure with common sense and judgement.

5.0 PREREQUISITES

SP69.Ø22.Ø1, Determination of Offsite Doses and/or SP69.Ø24.Ø1, Waterborne Release Dose Projection have been initiated.

6.0 LIMITATIONS AND ACTIONS

The Emergency Director/Response Manager must approve of a protective action before it is given to offsite authorities.

7.0 MATERIALS AND EQUIPMENT

N/A

8.0 PROCEDURE

8.1 Waterborne Protective Actions

8.1.1 Dose Assessment Staff Member or In-plant Radiation Monitoring Technician, perform the following:

8.1.1.1 Compare projected swimming (whole body and skin) and boating doses obtained from SP 69.Ø24.Ø1, Waterborne Release Dose Projection with the Waterborne Protective Action Guidance Chart (Appendix 12.1).

8.1.1.2 After consultation with the Radiation Protection Manager /Radiological Control Manager (if available), give the filled out worksheets (Appendix 12.1 and SPF 69.Ø24.Ø1-1) to the Emergency Director/Response Manager for subsequent approval and transmission to offsite authorities in accordance with SP69.ØØ9.Ø1, Notifications.

8.2 Airborne Protective Actions

8.2.1 Dose Assessment Staff Member or In-plant Radiation Monitoring Technician, complete the Airborne Protective Action Guide Worksheet (Appendix 12.2) as follows:

8.2.1.1 Obtain distance (item 1a), direction and affected downwind sector (item 1b), expected release duration (item 2), ground or elevated windspeed (item 3) and projected doses (item 10) from SP69.Ø22.Ø1, Determination of Offsite Doses.

8.2.1.2 Using the distance (item 1a), the affected downwind sector (item 1b) along with the Protective Action Map (Appendix 12.5) determine the zone (item 1c).

8.2.1.3 Calculate the plume travel time (item 4).

8.2.1.4 Contact the Control Room and determine the time the release started (item 5b) or the time the release is expected to start (item 5g).

8.2.1.5 Enter the current time (item 5c or item 5h) and complete the remaining items (either items 5d-e or 5i-j) for the appropriate situation.

8.2.1.6 Determine the prevailing weather conditions and circle this in item 6. Adverse weather consists of conditions which will significantly reduce traffic speeds, such as rain or light snow. If severe weather (e.g., flooding or blizzard) conditions exist a separate evacuation time will have to be estimated.

8.2.1.7 Determine the evacuation time and record this in item 7. The evacuation time is found by turning to the correct table of Appendix 12.3 for the prevailing weather conditions (items 6a and 6b). Then with the affected downwind sector (item 1b), find the left most value that contains the zone (item 1c) and pick the evacuation time for either day or night (item 6c) conditions.

8.2.1.8 Complete items 8 and 9 to determine the time a person evacuating will be exposed to the plume (evacuation exposure period).

8.2.1.9 If field monitoring teams are deployed near the area of concern, record the whole body dose rate and thyroid dose commitment values in item 11.

NOTE: Thyroid dose commitment is obtained by converting air sampler cpm readings by use of SP69.Ø23.Ø1, Thyroid Dose Commitment using the TCS Sampler.

8.2.1.10 Determine most reliable projected dose (item 12) based upon reliability of field team measurements (if available). Record the projected dose (item 12) on SPF69.Ø22.Ø1-2 Tabulated Dose and Protective Action Worksheet.

8.2.1.11 Complete items 13-15, and circle the higher recommended protective action for item 16. Record these on the Tabulated Dose and Protective Action Worksheet SPF69.Ø22.Ø1-2.

8.2.1.12 Record the protective action on the Protective Action Map (Appendix 12.5).

8.2.1.13 Repeat this procedure for other distances used in SP69.Ø22.Ø1 Determination of Offsite Doses

.1 Consider recommending the same protective action for adjacent zones.

.2 Consider recommending the same protective action for adjacent zones as distance from the plant increases.

8.2.1.14 After consultation with the Radiation Protection Manager/Radiological Control Manager (if available) give the completed worksheets (Appendix 12.5 and SPF 69.Ø22.Ø1-2) to the Emergency Director/Response Manager for subsequent approval and transmission to offsite authorities in accordance with SP69.ØØ9.Ø1 Notifications.

9.0 ACCEPTANCE CRITERIA

N/A

10.0 FINAL CONDITIONS

A protective action recommendation has been determined and approved by the Emergency Director/Response Manager.

11.0 REFERENCES

11.1 Shoreham Nuclear Power Station Emergency Plan

11.2 SP69.Ø22.Ø1, Determination of Offsite Doses

11.3 SP69.Ø24.Ø1, Waterborne Release Dose Projection

11.4 SP69.Ø23.Ø1, Thyroid Dose Commitment using the TCS Air Sampler

11.5 SP69.ØØ9.Ø1, Notifications

12.0 APPENDICES

12.1 Waterborne Protective Action Guidance Chart

12.2 Airborne Protective Action Guide Worksheet, SPF69.Ø26.Ø1-1

12.3 Evacuation Times by Wind Direction

12.4 Shielding Factors from a Gamma Cloud Source

12.5 Thyroid and Whole Body Guidance Charts

12.6 Protective Action Map, SPF69.Ø26.Ø1-2

WATERBORNE PROTECTIVE ACTION GUIDANCE CHART

IF	THEN
Projected whole body or skin dose due to swimming is equal to or greater than 1 rem.	Instruct the U.S. Coast Guard to remove all swimmers within a 1 mile distance of the plant
Projected whole body dose due to boating is equal to or greater than 1 rem.	Instruct the U.S. Coast Guard to evacuate all boats and vessels within a 1 mile distance of the plant

AIRBORNE PROTECTION ACTION GUIDE WORKSHEET

1. Area of Concern

   a. Distance ________miles (from SP69.Ø22.Ø1)
   b. Direction ________degrees, Affected Downwind Sector_____(from SP69.Ø22.Ø1)
   c. Zone ________(A-S, from Appendix 12.6)

2. Expected release duration__________hrs (from SP69.Ø22.Ø1)

3. Windspeed ________________miles/hr (from SP69.Ø22.Ø1)

   NOTE: For ground releases use 33 ft. windspeed; for elevated releases use 150 ft. windspeed.

4. Plume travel time = item la/item 3

   = ___________ / __________ = __________hours

5. Time until exposure begins (choose a or f)

   a. If release has begun:

      b. Time release has started_________(use 24 hour clock)
      c. Time of calculation__________(use 24 hours clock)
      d. Time difference = item 5c - item 5b = __________hrs.
      e. Time = item 4 - item 5d = ____________hrs.

      NOTE: If item 5e is a negative number, enter zero hours.

   f. If release will begin later:

      g. Time release is expected to start__________(use 24 hour clock)
      h. Time of calculation_________ (use 24 hr clock)
      i. Time difference = item 5g - item 5h = __________hrs.
      j. Time = item 4 + item 5i = __________hrs.

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6. Weather condition and season (circle one for a,b and c):

   a. Ideal Adverse Severe
   b. Seasonal Non-Seasonal
   c. Day Night

7. Evacuation time:

   Use Appendix 12.3 along with information recorded in items 1 and 6 to determine the evacuation time. See procedure Step 8.2.1.7.

   Evacuation time _____hrs.

8. Exposure time = item 7 - (item 5a or 5f)

   = _________ - _________ = __________hrs.

   NOTE: If item 8 is negative, enter zero hours.

9. Evacuation Exposure Period:

   Smaller of item 8 or item 2: __________hrs.

	THYROID	WHOLE BODY
10. Projected Dose (from SP69.Ø22.Ø1)	10.______rem	10.______rem
11. Measured dose from field monitoring teams (if applicable):		
Monitoring Team Dose Rate X item 2		
______rem/hr WB x ______hrs.		11.______rem
Thyroid Dose Commitment from TCS Air Sampler (from SP69.Ø23.Ø1)	11.______rem	

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	THYROID	WHOLE BODY
*12. Most reliable projected dose (item 10 or 11)	12.______rem	12.______rem

*13. Evacuation Dose

item 9 x item 12/item 2

_____ x _____ / ____(Thy.) 13.______rem

_____ x _____ / ____(WB) 13.______rem

*14. Shelter Dose

Thyroid (a or b)

a. For item 2 less than or equal to 2 hours

item 12 x 0.33 = ________ x 0.33

b. For item 2 greater than 2 hours

$$\text{item 12} \times \left(1 - \frac{1.34}{\text{item 2}}\right)$$

$$\_\_\_\_\_\_ \times \left(1 - \frac{1.34}{\_\_\_\_}\right)$$

14.______rem
(a or b)

Whole Body

Item 12 x Structural Shielding Factor
(Appendix 12.4)

________ x _________ 14.______rem

*Record these valves on SPF 69.Ø22.Ø1-2

SPF 69.Ø26.Ø1-1 Rev. Ø

	THYROID	WHOLE BODY
*15. Refer to the Thyroid and Whole Body Guidance Charts (Appendix 12.5) and Circle the appropriate action for each	No Action	No Action
	Shelter	Shelter
	Evacuate	Evacuate

*16. Protective Action Recommendation (Circle One)

No Action   Shelter   Evacuate

17. Indicate item 16 on the Protective Action Map (Appendix 12.6) for the affected zone

* Record these values on SPF 69.Ø22.Ø1-2

SPF 69.Ø26.Ø1-1 Rev. Ø

EVACUATION TIMES BY WIND DIRECTION

SEASONAL (IDEAL CONDITIONS)

	0-2 MILES			0-5 MILES			0-10 MILES		
WIND DIRECTION (toward)	ZONE(S)	WEEK DAY	WEEK NIGHT	ZONES	WEEK DAY	WEEK NIGHT	ZONES	WEEK DAY	WEEK NIGHT
W by WNW	A	2.25	2.25	AF	5.08	5.08	AFKQ	5.58	5.58
W	A	2.25	2.25	AFG	5.08	5.08	AFGKQ	5.58	5.58
W by WSW	AB	2.50	2.50	ABFG	5.08	5.08	ABFGKQ	5.58	5.58
WSW	AB	2.50	2.50	ABFG	5.08	5.08	ABFGKQL	5.58	5.58
WSW by SW	AB	2.50	2.50	ABFG	5.08	5.08	ABFGKRL	5.17	5.17
SW	AB	2.50	2.50	ABG	3.00	3.00	ABGKRLM	4.33	4.33
SW by SSW	ABC	2.50	2.50	ABCGH	4.83	4.83	ABCGHKRLM	4.67	4.67
SSW	ABC	2.50	2.50	ABCGH	3.17	4.83	ABCGHRLMN	5.00	5.00
SSW by S	BC	2.42	2.42	BCGH	3.17	3.17	BCGHLMN	3.17	3.17
S	BC	2.42	2.42	BCGHI	3.17	3.17	BCGHIMNO	3.67	3.17
S by SSE	CD	2.17	2.17	CDHI	3.17	2.67	CDHIMNO	3.67	2.75
SSE	CD	2.17	2.17	CDHI	3.17	2.67	CDHINO	3.67	2.75
SSE by SE	CD	2.17	2.17	CDHI	3.17	2.67	CDHINO	3.67	2.75
SE	CDE	2.25	2.25	CDEIJ	4.67	4.08	CDEIJOS	4.67	3.83
SE by ESE	CDE	2.25	2.25	CDEIJ	4.67	4.08	CDEIJOPS	4.67	3.83
ESE	CDE	2.25	2.25	CDEIJ	4.67	4.08	CDEIJOPS	4.67	3.83
ESE by E	DE	2.17	2.17	DEIJ	4.67	4.08	DEIJOPS	4.67	3.83
E	E	2.00	2.00	EJ	4.00	3.33	EJOPS	4.08	3.33
E by ENE	E	2.00	2.00	EJ	4.00	3.33	EJP	4.08	3.33
NO WIND	ABCDE	2.50	2.50	N/A			N/A		

TIMES ARE EXPRESSED IN HOURS AND INCLUDE 20 MIN. FOR MOBILIZATION

EVACUATION TIMES BY WIND DIRECTION

NON-SEASONAL (IDEAL CONDITIONS)

WIND DIRECTION (toward)	0-2 MILES ZONE(S)	0-2 MILES WEEK DAY	0-2 MILES WEEK NIGHT	0-5 MILES ZONES	0-5 MILES WEEK DAY	0-5 MILES WEEK NIGHT	0-10 MILES ZONES	0-10 MILES WEEK DAY	0-10 MILES WEEK NIGHT
W by WNW	A	1.83	1.83	AF	4.75	4.75	AFKQ	5.33	5.33
W	A	[illegible].83	1.83	AFG	4.75	4.75	AFGKQ	5.33	5.33
W by WSW	[illegible]	2.50	2.50	ABFG	4.75	4.75	ABFGKQ	5.33	5.33
WSW	AB	2.50	2.50	ABFG	4.75	4.75	ABFGKQL	5.33	5.33
WSW by SW	AB	2.50	2.50	ABFG	4.75	4.75	ABFGKRL	4.92	4.92
SW	AB	2.50	2.50	ABG	3.00	3.00	ABGKRLM	3.92	3.92
SW by SSW	ABC	2.50	2.50	ABCGH	4.58	4.33	ABCGHKRLM	4.17	4.17
SSW	ABC	2.50	2.50	ABCGH	4.58	4.33	ABCGHRLMN	4.58	4.58
SSW by S	BC	2.42	2.42	BCGH	3.17	3.17	BCGHLMN	3.17	3.17
S	[illegible]C	2.42	2.42	BCGHI	3.17	3.17	BCGHIMNO	3.17	3.17
S by SSE	CD	1.33	1.33	CDHI	2.33	1.75	CDHIMNO	2.83	2.25
SSE	CD	1.33	1.33	CDHI	2.33	1.75	CDHINO	2.83	2.25
SSE by SE	CD	1.33	1.33	CDHI	2.33	1.75	CDHINO	2.83	2.25
SE	CDE	1.67	1.67	CDEIJ	2.83	2.83	CDEIJOS	2.83	2.83
SE by ESE	CDE	1.67	1.67	CDEIJ	2.83	2.83	CDEIJOPS	2.83	2.83
ESE	CDE	1.67	1.67	CDEIJ	2.83	2.83	CDEIJOPS	2.83	2.83
ESE by E	DE	1.67	1.67	DEIJ	2.83	2.83	DEIJOPS	2.83	2.83
E	E	1.50	1.50	EJ	2.33	2.33	EJOPS	2.23	2.33
E by ENE	E	1.50	1.50	EJ	2.33	2.33	EJP	2.33	2.33
NO WIND	ABCDE	2.50	2.50	N/A			N/A		

TIMES ARE EXPRESSED IN HOURS AND INCLUDE 20 MIN. FOR MOBILIZATION

EVACUATION TIMES BY WIND DIRECTION

SEASONAL (ADVERSE CONDITION)

WIND DIRECTION (toward)	0-2 MILES ZONE(S)	0-2 MILES WEEK DAY	0-2 MILES WEEK NIGHT	0-5 MILES ZONES	0-5 MILES WEEK DAY	0-5 MILES WEEK NIGHT	0-10 MILES ZONES	0-10 MILES WEEK DAY	0-10 MILES WEEK NIGHT
W by WNW	A	2.67	2.67	AF	6.08	6.08	AFKQ	6.67	6.67
W	A	2.67	2.67	AFG	6.08	6.08	AFGKQ	6.67	6.67
W by WSW	AB	3.00	3.00	ABFG	6.08	6.08	ABFGKQ	6.67	6.67
WSW	AB	3.00	3.00	ABFG	6.08	6.08	ABFGKQL	6.67	6.67
WSW by SW	AB	3.00	3.00	ABFG	6.08	6.08	ABFGKRL	6.17	6.17
SW	AB	3.00	3.00	ABG	3.58	3.58	ABGKRLM	5.17	5.17
SW by SSW	ABC	3.00	3.00	ABCGH	5.75	5.75	ABCGHKRLM	5.58	5.58
SSW	ABC	3.00	3.00	ABCGH	5.75	5.75	ABCGHRLMN	6.00	6.00
SSW by S	BC	2.83	2.83	BCGH	3.75	3.75	BCGHLMN	3.75	3.75
S	BC	2.83	2.83	BCGHI	3.75	3.75	BCGHIMNO	4.33	3.75
S by SSE	CD	2.58	2.58	CDHI	3.75	3.17	CDHIMNO	4.33	3.25
SSE	CD	2.58	2.58	CDHI	3.75	3.17	CDHINO	4.33	3.25
SSE by SE	CD	2.58	2.58	CDHI	3.75	3.17	CDHINO	4.33	3.25
SE	CDE	2.67	2.67	CDEIJ	5.58	4.83	CDEIJOS	5.58	4.58
SE by ESE	CDE	2.67	2.67	CDEIJ	5.58	4.83	CDEIJOPS	5.58	4.58
ESE	CDE	2.67	2.67	CDEIJ	5.58	4.83	CDEIJOPS	5.58	4.58
ESE by E	DE	2.58	2.58	DEIJ	5.58	4.83	DEIJOPS	5.58	4.58
E	E	2.33	2.33	EJ	4.75	4.00	EJOPS	4.83	4.00
E by ENE	E	2.33	2.33	EJ	4.75	4.00	EJP	4.83	4.00
NO WIND	ABCDE	3.00	3.00	N/A			N/A		

TIMES ARE EXPRESSED IN HOURS AND INCLUDE 20 MIN. FOR MOBILIZATION

EVACUATION TIMES BY WIND DIRECTION

NON SEASONAL (ADVERSE CONDITIONS)

WIND DIRECTION (toward)	0-2 MILES ZONE(S)	0-2 MILES WEEK DAY	0-2 MILES WEEK NIGHT	0-5 MILES ZONES	0-5 MILES WEEK DAY	0-5 MILES WEEK NIGHT	0-10 MILES ZONES	0-10 MILES WEEK DAY	0-10 MILES WEEK NIGHT
W by WNW	A	2.17	2.17	AF	5.67	5.67	AFKQ	6.33	6.33
W	A	2.17	2.17	AFG	5.67	5.67	AFGKQ	6.33	6.33
W by WSW	AB	3.00	3.00	ABFG	5.67	5.67	ABFGKQ	6.33	6.33
WSW	AB	3.00	3.00	ABFG	5.67	5.67	ABFGKQL	6.33	6.33
WSW by SW	AB	3.00	3.00	ABFG	5.67	5.67	ABFGKRL	5.83	5.83
SW	AB	3.00	3.00	ABG	3.58	3.58	ABGKRLM	4.67	4.67
SW by SSW	ABC	3.00	3.00	ABCGH	5.58	5.17	ABCGHKRLM	5.00	5.00
SSW	ABC	3.00	3.00	ABCGH	5.58	5.17	ABCGHRLMN	5.58	5.58
SSW by S	BC	2.83	2.83	BCGH	3.75	3.75	BCGHLMN	3.75	3.75
S	BC	2.83	2.83	BCGHI	3.75	3.75	BCGHIMNO	3.75	3.75
S by SSE	CD	1.58	1.58	CDHI	2.75	2.08	CDHIMNO	3.33	2.67
SSE	CD	1.58	1.58	CDHI	2.75	2.08	CDHINO	3.33	2.67
SSE by SE	CD	1.58	1.58	CDHI	2.75	2.08	CDHINO	3.33	2.67
SE	CDE	2.00	2.00	CDEIJ	3.33	3.33	CDEIJOS	3.33	3.33
SE by ESE	CDE	2.00	2.00	CDEIJ	3.33	3.33	CDEIJOPS	3.33	3.33
ESE	CDE	2.00	2.00	CDEIJ	3.33	3.33	CDEIJOPS	3.33	3.33
ESE by E	DE	2.00	2.00	DEIJ	3.33	3.33	DEIJOPS	3.33	3.33
E	E	1.75	1.75	EJ	2.75	2.75	EJOPS	2.75	2.75
E by ENE	E	1.75	1.75	EJ	2.75	2.75	EJP	2.75	2.75
NO WIND	ABCDE	3.00	3.00	N/A			N/A		

TIMES ARE EXPRESSED IN HOURS AND INCLUDE 20 MIN. FOR MOBILIZATION

REPRESENTATIVE SHIELDING FACTORS FROM GAMMA CLOUD SOURCE (1)

STRUCTURE OR LOCATION	SHIELDING FACTOR (a)	REPRESENTATIVE RANGE
Outside	1.0	---
Vehicles	1.0	---
Wood-frame house (b) (no basement)	0.9	---
Basement of wood house	0.6	0.1 to 0.7 (c)
Masonry house (no basement)	0.6	0.4 to 0.7 (c)
Basement of masonry house	0.4	0.1 to 0.5 (c)
Large office or industrial building	0.2	0.1 to 0.3 (c), (d)

(a) The ratio of the dose received inside the str[illegible] [illegible] the dose that would be received outside the structure.

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

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

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

(1) Ref: Sand 77-1725 (Unlimited Release)

THYROID GUIDANCE CHART

IF	THEN
Projected dose (Item 12) is less than 5 rem	No action
Shelter dose (Item 14) is less than 25 rem	Shelter* for children and women of childbearing age.
Shelter dose (Item 14) equal to or greater than 25 rem and evacuation dose (Item 13) equal to or greater than shelter dose.	Shelter*
Sheltr dose (Item 14) equal to or greater than 25 rem and evacuation dose (Item 13) less than shelter dose.	Evacuate

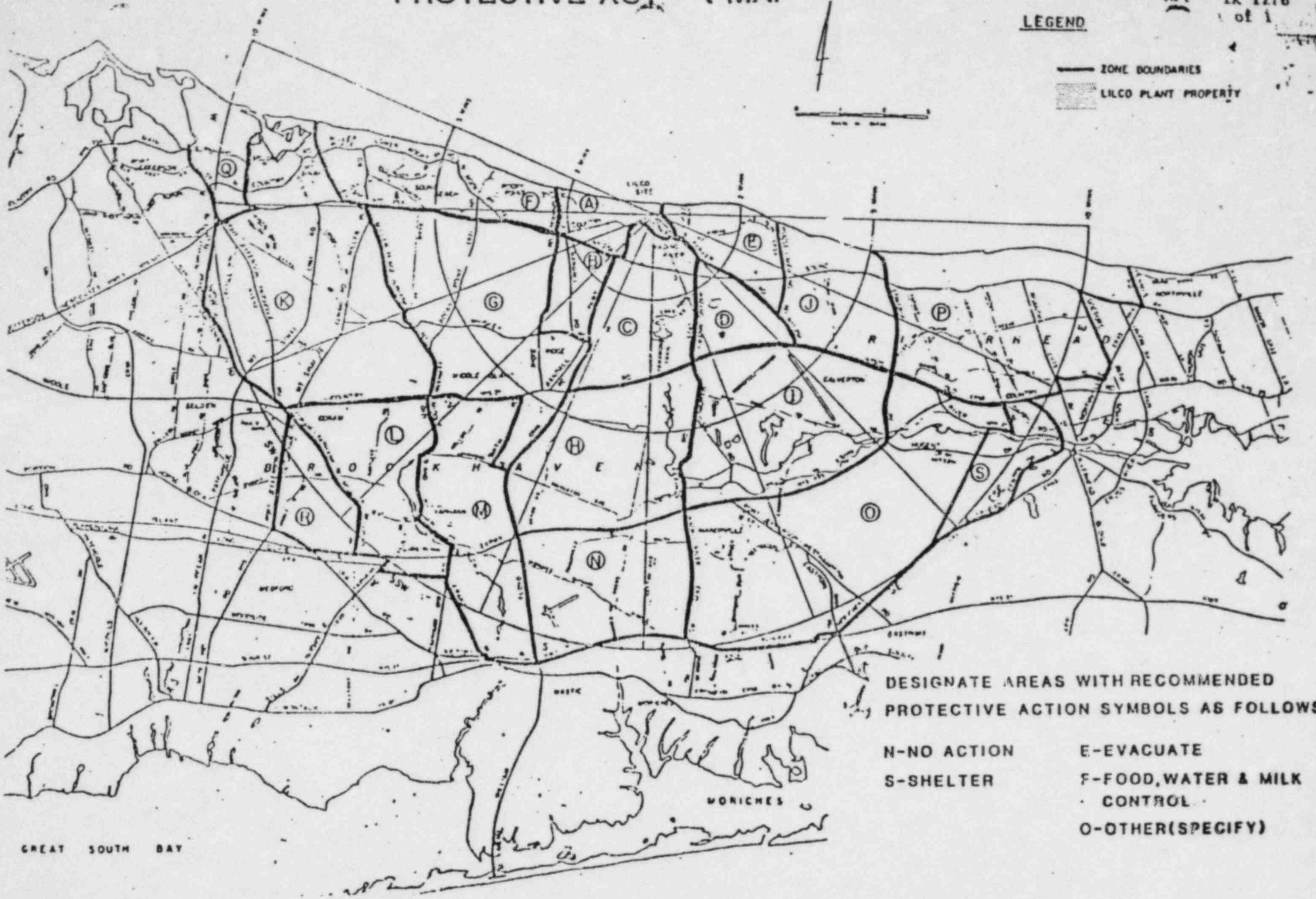
Shelter is to be with ventilation control. Ventilation control means turning off air conditioners or fans, closing doors and windows thus preventing access of outside air.

WHOLE BODY GUIDANCE CHART

IF	THEN
Projected dose (Item 12) less than 1 rem	No Action
Shelter dose (Item 14) less than 5 rem	Shelter*
Shelter dose (Item 14) equal to or greater than 5 rem and evacuation dose (Item 13) equal to or greater than shelter dose.	Shelter*
Shelter dose (Item 14) equal to or greater than 5 rem and evacuation dose (Item 13) less than shelter dose.	Evacuate

*Shelter is to be with ventilation control. Ventilation control means turning off air conditioners or fans, closing doors and windows thus preventing access of outside air.

PROTECTIVE ACTION MAP



DESIGNATE AREAS WITH RECOMMENDED PROTECTIVE ACTION SYMBOLS AS FOLLOWS:

N-NO ACTION
S-SHELTER
E-EVACUATE
F-FOOD, WATER & MILK CONTROL
O-OTHER(SPECIFY)

Attachment 10(B) - 7

AIF/NESP-023

National
Environmental
Studies
Project

Evaluation of an Environs Exposure Rate Monitoring System for Post-Accident Assessment

Atomic Industrial Forum, Inc.

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AIF/NESP-023

EVALUATION OF AN ENVIRONS EXPOSURE RATE MONITORING SYSTEM FOR POST-ACCIDENT ASSESSMENT

Prepared for the
National Environmental Studies Project
of the
Atomic Industrial Forum, Inc.

by

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December 1981

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PREFACE

The accident at Three Mile Island prompted the Nuclear Regulatory Commission to propose substantial changes to Revision 2 of Regulatory Guide 1.97, and a draft including these changes was published in December, 1979. Among other things this draft document called for the presence of a ring of permanently installed, automatic radiation monitors around nuclear power plants. These monitors were to be sensitive over a very wide range (1 μR/hr to 10 R/hr), and capable of providing real time information on accidental releases from both monitored and unmonitc ed points in the plant.

The purpose of this study, begun in the summer of 1980, was to examine the ramifications of the proposed new requirements in the light of both costs and the technical limitations of the equipment available "off-the-shelf" at that time. While this NESP study was being developed, the proposed draft to Revision 2 of Regulatory Guide 1.97 was considerably revised as a result of the review process, and reissued in December, 1980. This latest version left wide latitude to utilities with regard to the approach used in obtaining post-accident monitoring information. Specifically, a fixed array of exposure rate monitors was no longer required.

This NESP study concludes that no system of instrumentation commercially available in August, 1980, could have met the requirements of the December, 1979 draft of Revision 2 of Regulatory Guide 1.97. The study further identifies the nature of the shortcomings of the systems evaluated. This is not to say that fixed monitors cannot provide valuable information, especially in the early stages of a radiological emergency prior to the arrival of mobile survey teams. Furthermore, several vendors have recently devoted considerable effort to developing more effective equipment. Where the difficulties inherent in fixed monitors can be overcome they may, in some instances, prove to be effective in meeting the intent of the requirements in the current version of Regulatory Guide 1.97.

This study was designed and guided by the NESP Task Force listed on the inside front cover. Special thanks are due the Task Force's co-chairmen Gerald R. Davidson, who coordinated the final reviews, and Kevin Rooney, who guided the study in the beginning and has continued to contribute significantly to it. Also deserving credit for providing comments and recommendations are the AIF Subcommittee on Emergency Preparedness and Siting Policy, chaired by Steven J. Miliott of American Electric Power Service Corporation, and Paul J. Pettit, now of Halliburton Services, who preceded me as NESP Project Manager and Secretary for the Task Force. Finally, the information and assistance provided by the vendors listed in Appendix A, especially the Harshaw Chemical Company and Reuter-Stokes Inc., are most gratefully acknowledged.

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SUMMARY

Introduction

The Three Mile Island accident initiated an extensive review of post-accident systems required for nuclear power plant operation. Following this review, the Nuclear Regulatory Commission proposed revisions to Regulatory Guide 1.97, "Instrumentation For Light Water Cooled Nuclear Power Plants To Assess Plant and Environs Conditions During and Following An Accident" (1). Among the proposed revisions was the requirement for an environs monitoring system.

Although the environs monitoring system was proposed for post-accident monitoring, a lower detection limit of 1 μR/hr was specified. This lower limit was presumably chosen on the assumption that a single detector would be used and that such a lower limit would insure a positive detector reading at all times.

Study Goals

This study examined an environs monitoring system only as it relates to post accident monitoring. It did not consider the merit of such a system for other purposes such as environmental monitoring. The study addressed the following six aspects:

1. Availability of Instrumentation

   An evaluation was made in mid-1980 to determine the availability of environmental radiation monitoring systems to meet the applicable requirements being considered in 1980 for Revision 2 to Regulatory Guide 1.97 and to determine if the range 1 μR/hr to 10 R/hr could be met with a single detector.

2. Dose Rate Projection

The study investigated the use of environs monitoring system data to project dose rates at other locations.

3. Response of a System to Accident Conditions

The response of an environs monitoring system to an accident condition was evaluated for a design basis accident. Also investigated were the responses under actual meteorology to the accident at Three Mile Island and to a hypothetical accident at a boiling water reactor (BWR).

4. Release Rates From Unmonitored Pathways

The study addressed the feasibility of using an environs monitoring system for the purpose stated in an early draft of Revision 2 to Regulatory Guide 1.97:

> "For estimating release rates of radioactive materials released during an accident from unidentified release paths (not covered by effluent monitors)...."

5. Number of Stations Required to Determine Maximum Plume Exposure Rate

An investigation was made of the number of stations required to enable determining the maximum plume exposure rate (i.e., the rate directly under the plume centerline) within a factor of two.

6. Costs

The final objective of this study was to estimate the costs of an environs monitoring system.

Conclusions

The following summarizes the results of this study:

1. Availability of Instrumentation

As of August 1980, no system was available "off the shelf" that could measure over the range 1 μR/hr to 10 R/hr with a single detector. Nor was there available any system of multiple detectors covering this range with each detector providing a positive reading at all times.

2. Dose Rate Projection

Using data from an environs monitoring system to project dose rates at other locations is a two-step process. The first step is to deduce a source term from the environs data. The second is to make projections using this source term. Making accurate projections would be extremely difficult and in some cases impossible because it would require accurately knowing:

a. either plume centerline dose rate or location of the plume centerline relative to the detectors;
b. effective heights of all releases (monitored and unmonitored);
c. energy compositions of releases;
d. shine contributions to detector dose rates due to contained sources (e.g., airborne activity on BWR refueling floor);
e. meteorological stability class;
f. local meteorological phenomena (e.g., looping, fumigation).

3. Response of a System to Accident Conditions

a. Response for Actual Meteorology

For actual meteorology at Three Mile Island and at a typical BWR, we found large fluctuations in dose rates that would be measured by fixed environs detectors. Peak readings of a 16-detector system would change by a factor of 10 or more without any significant change in release rate. This would complicate the problems of following accident trends and of detecting releases by unmonitored paths.

b. BWR Shine

For a Mark I or Mark II BWR, shine from the refueling floor could produce dose rates comparable to plume centerline dose rates for close-in detectors. This would complicate data interpretation and make more difficult the detection of releases by unmonitored paths.

c. Design Basis Accident

We examined a postulated design basis accident with a direct 1%/day leak rate from primary containment to the environs. At 250 m the peak dose rate was approximately one-tenth the 10 R/hr upper limit specified by the NRC. This was for the

worst case considered (Class F meteorology, ground level release, 3 m/sec wind speed). Therefore, 10 R/hr appears to be a reasonable upper limit at this radius for monitoring a design basis accident of this type.

4. Release Rates From Unmonitored Pathways

a. In the Absence of Monitored Releases

If there were no monitored releases and no shine from contained sources, an environs monitoring system would be 10 to 50,000 times less sensitive than a typical stack monitor. Furthermore, unless one knew the release height and the plume centerline location relative to the detectors, there could be considerable uncertainty in the release rate deduced from environs monitoring system measurements.

b. In the Presence of Monitored Releases

Monitored releases from our postulated design basis accident would decrease the sensitivity for detection of additional unmonitored releases by several orders of magnitude. To determine the size of an unmonitored release, effects of known releases would have to be accurately calculated and subtracted. In most practical circumstances, it would be nearly impossible to detect an unmonitored release in the presence of monitored releases.

5. Number of Stations Required to Determine the Maximum Plume Exposure Rate

We analyzed the response of a ring of 16 detectors to a Class F 80-KeV ground level release passing halfway between two detectors. For rings of radii 250 to 1000 m, none of the detectors would read within a factor of two of the dose rate below the plume centerline. We were unsuccessful in attempts to find a mathematical fitting function that would enable determination of the centerline dose rate within a factor of 2 for all stability classes. In our 1980 market survey, we found no vendor who had available a data analysis program to accomplish this.

6. Costs

For a ring of 16 detectors and associated central processing equipment, we estimate the following costs in 1980 dollars:

Equipment: $226,000 to $364,000

Installation: $40,000 to $2,000,000

In addition, the cost for annual operation and maintenance should be included.

The wide variance in the installation costs primarily results from individual site requirements which can greatly affect the cost, particularly for hard wired systems.

Section 1

1.0 IDENTIFICATION OF COMMERCIALLY AVAILABLE INSTRUMENTATION

1.1 APPROACH

To determine the availability of commercial equipment to meet the requirements of an early draft of Revision 2 to Regulatory Guide 1.97 (1), a very brief questionnaire was sent to forty-nine possible vendors. Thirteen of these were contacted by telephone as well as by letter. The questionnaire, the mailing list and a list of those contacted by telephone are included in Appendix A. Each vendor was also requested to provide literature describing an appropriate system. All of the vendors contacted responded.

As a result of the survey two vendors were visited to examine their facilities and further discuss their capabilities. On August 6, 1980 we met with personnel from Harshaw Chemical Company, a supplier of a system using NaI(Tl) detectors but who propose to use CaF_2 scintillation detectors. The following day we met with Reuter-Stokes who provide a system using two ion chambers.

1.2 FINDINGS

The results of our study indicate that as of August, 1980:

- No system was available "off the shelf" that could meet the projected requirements.
- Two suppliers, Harshaw and Reuter-Stokes, had manufactured and delivered systems having similar but not identical specifications. Their emphasis had been on routine low level environmental monitoring rather than on accident monitoring.
- One supplier, PAR Systems Corporation, had a system available using two energy compensated Geiger Counters.
- Many vendors were considering adding such a system to their product lines when the requirements and specifications became firm.

- Some vendors stated that they would accept orders to build such systems as special orders but only according to detailed specifications of customers.
- No vendor had addressed the problem of data reduction, presentation or interpretation. They provided chart recordings or data listings from each detector station. Any additional data reduction would be up to the user.
- Both vendors visited stated that they intended for the future to make on-site maintenance available to customers but neither currently provided a "fast action" repair service.

1.3 SYSTEMS OFFERED BY THE TWO VENDORS VISITED

1.3.1 Harshaw

Harshaw felt they could meet the desired range from 10^{-6} R/hr to 10 R/hr with a single CaF_2 scintillator detector operated in the current mode rather than pulse mode. Although they had not yet produced such a system, they appeared to have developed most of the required components. A perimeter monitoring system was part of their marketing plan.

Their system as then envisioned consisted of a remote station with the CaF_2 detector, a battery backed up power supply and a local microprocessor hard wired to a central station. The central station would contain an adjustable high voltage power supply for each remote station. Plans called for the remote stations to be monitored in sequence, but the system could be altered to provide simultaneous individual interrogation. The use of the single detector would satisfy the NRC desire to have a system that, when functioning, always gives a positive reading. The remote unit was small: the detector was about 3" in diameter and 7" long and the electronics were in an 8" x 8" x 12" box.

Harshaw was marketing an environmental system, TASC-4, capable of remotely monitoring fields from 1 μR/hr to 10 mR/hr. The detectors had alpha stabilized gain (implanted ^{241}Am source) and were operated as pulse counters. The systems already delivered supplied an analog signal to a panel meter or strip chart recorder at a central location and had limited data reduction capability.

TASC-4 systems had been supplied to two utilities in the U.S. and a number of overseas companies.

1.3.2 Reuter Stokes

Reuter Stokes was marketing a system, Sentri 1011, which used two detectors to monitor the range from 10^{-6} to 10 R/hr. A high-pressure ionization chamber (HPIC) was used to measure fields from 1 μR/hr to 100 mR/hr. This detector had two ranges with automatic switching in the electrometer. Radiation fields from 10 mR/hr to 10 R/hr were measured with a smaller ionization chamber. A remote station consisted of the two detectors, a power supply with a back-up battery, the range changer, a strip chart recorder, a digital display and data transmitter. Data transmittal could be by hard wire, telephone or telemetry. The central processor consisted of a computer with a storage device and printer. Reports could be generated on a schedule as well as on operator command. The system handled up to sixteen stations and interrogation of the remotes was through a direct link to each station. The system provided a continuous positive active response from only the low-range detector. The high range detector could be provided with an internal beta-emitting source to provide positive indication that the high range chamber was functioning properly. A practical way to provide continuous assurance that the electrometer switching device was functional had not been conceived.

Two systems were to be delivered soon to eastern utilities. Both systems were to have a central processor with telephone links to sixteen stations at one and to ten stations at the other. Another system of ten stations was soon to be delivered without a central processor. Processing for this system was to be by a plant computer. In addition to these they planned to deliver two more systems of eight stations in the fall of 1980. Both would link to the plant computer. None of these systems was a telemetered system but Reuter Stokes had done some work with telemetry and was setting up a telemetering link between two of their buildings in Solon, Ohio. They felt that two miles would be a comfortable distance for such a system. One problem they had encountered in their telephone transmittal systems was the inability of the telephone company to provide connections for an outdoor environment.

1.4 SYSTEMS OFFERED BY OTHER VENDORS

PAR Systems offered a complete system that was manufactured in Britain and was not visited. Although a number of other vendors supplied information on available detectors, none offered a complete system package. Other than those previously mentioned, five vendors stated that they could provide two detectors that would meet the range 1 μR/hr to 10 R/hr. Five respondents indicated that they had a detector capable of measuring 10 R/hr with a lower limit greater than 1 μR/hr. Of these, three had a lower limit of 1000 μR/hr, one was 100 μR/hr and the fifth was 10 μR/hr.

1.5 CALIBRATION

Both Harshaw, using a CaF_2 current output system, and Reuter Stokes, using a pair of ion chambers, had detectors whose responses were approximately energy independent. Calibration could be accomplished by cross calibration with any chamber calibrated to yield accurate exposure rates or using a gamma ray standard.

Harshaw had calibration facilities that they used to calibrate and control their TLD production and service work. They had a ^{60}Co source that they had calibrated to be a secondary standard through the use of air cavity ionization chambers that were cross-calibrated at the National Bureau of Standards. They seemed to have a fair grasp on the necessity and requirements of the calibration process. They believed that systems supplied by them should be field calibrated semiannually.

Reuter Stokes used procedures developed by DOE (HASL) for the calibration of the HPIC. They also depended on Victoreen Instrument Company for calibration services. Reuter Stokes had a HPIC calibrated by Victoreen that was used as a secondary standard. All chambers marketed by Reuter Stokes were being calibrated by referencing to this standard chamber.

1.6 ENVIRONMENTAL QUALIFICATION

The two vendors felt that a system could be qualified to IEEE Standard 323-1974. However, neither was willing to state that its instrumentation was qualified to this standard. Of major importance in this reluctance was the requirement for aging, a generic problem.

IEEE Standard 323-1974 provides guidance for demonstrating qualification of Class 1E equipment. For equipment not located in containment and not subject to the extreme post LOCA environment, it can be interpreted to say that it should be shown that "the equipment can operate reliably under conditions that it is likely to encounter". These conditions are not severe for this type of equipment and both Reuter Stokes and Harshaw have had experience with systems in the field. They both felt that they could qualify their systems to meet the conditions that would be found in field operations.

Section 2

2.0 CRITERIA FOR LOCATION OF REMOTE STATIONS

A parametric study to evaluate the detector response under different assumed accident conditions attempted to establish criteria for location of the remote monitoring stations. The location criteria include the requirement that the system be capable of determining, within a factor of two, the maximum dose rate on the ground directly under the plume at the radius of the detector ring.

2.1 DESCRIPTION OF THE MODEL EMPLOYED

A finite plume model was developed to do this study that was based on the concentrations obtained with the Pasquill-Gifford (2) model for atmospheric diffusion. This model calculates the exposure rate at any detector location for any given release rate and gamma-ray energy. The commonly accepted expression "dose rate" is subsequently used for exposure rate in this report.

The concentration, $\chi \left(\frac{Ci}{m^3}\right)$, is dependent on atmospheric conditions (wind speed and stability class), release height and release rate (Ci/s). The concentration and, therefore, the dose rate is directly proportional to the release rate and inversely proportional to the wind speed. The model was used to compute the dose rate per unit release rate (R/hr)/(Ci/s) at a unit wind speed (1 m/s). The dose rate under specific conditions is then determined from the calculated value by multiplying by the actual release rate (in Ci/s) and dividing by the wind speed (in m/s).

The plume concentrations were computed using Equation (1) from Reference 2.

$$\chi(x,y,z) = \frac{Q\,G(z)}{2\pi\sigma_y\sigma_z\bar{u}} \exp\left(-\tfrac{1}{2}(y/\sigma_y)^2\right) \tag{1}$$

where

$$G(z) = \exp\left(-\tfrac{1}{2}\left((z-H)/\sigma_z\right)^2\right) + \exp\left(-\tfrac{1}{2}\left((z+H)/\sigma_z\right)^2\right) \tag{2}$$

χ = nuclide concentration (Ci/m^3),
Q = nuclide release rate (Ci/s),
$\bar{u}$ = average wind speed (m/s),
σ_y = horizontal atmospheric diffusion parameter (m),
σ_z = vertical atmospheric diffusion parameter (m),
H = height of release (m), and
x,y,z = coordinates of point at which the concentration is computed.

The dose rate at the detector can then be obtained by using a point source approximation and integrating over the source distribution.

The exposure rate is given by:

$$\dot{D}\left(\frac{R}{hr}\right) = C\,\frac{\mu_a}{\rho}\,E_o\,B(\mu R)\,\Gamma, \tag{3}$$

where

$C = 6.87 \times 10^{-5}\left(\frac{R\text{-}g\text{-}s}{MeV\text{-}hr}\right)$,
$\frac{\mu_a}{\rho}$ = mass absorption coefficient for air at energy E_o (m^2/g),
E_o = energy per photon MeV/photon,
$B(\mu R)$ = buildup factor, and
Γ = uncollided photon flux $\left(\frac{photons}{m^2\text{-}s}\right)$

The uncollided photon flux Γ is:

$$\Gamma\left(\frac{photons}{m^2\text{-}s}\right) = \frac{S}{4\pi R^2}\,e^{-\mu R} \tag{4}$$

where

S = photon emission rate (photons/s),

R = distance from source (m), and

μ = total linear attenuation coefficient for air (m^{-1}).

The photon emission rate, S, can be found by assuming a small volume, dV, at concentration χ as follows:

$$S \text{ (photons/s)} = 3.7 \times 10^{10} \chi I_k dV, \quad (5)$$

where

3.7×10^{10} = the number of disintegrations per second per Ci,

χ = radionuclide concentration in the small volume element $dV(Ci/m^3)$,

I_k = number of photons of energy E_o per disintegration, and

dV = volume element considered (m^3).

Combining equations 4 and 5 with equation 3 gives:

$$\dot{D}\left(\frac{R}{hr}\right) = \frac{2.54 \times 10^6}{4\pi R^2} \frac{\mu_a}{\rho} E_o I_k \chi e^{-\mu R} B(\mu R) dV, \quad (6)$$

which is the contribution to the exposure rate at the detector due to the small volume element dV. The total exposure rate is obtained by integration over volume of the plume. Calculational convergence criteria reduced computational time.

In the parametric study $\chi\bar{u}/Q$ was used in Equation (6) rather than χ. This produced an answer in terms of $\dot{D}\bar{u}/Q$ or dose rate per unit release rate (R/hr)/(Ci/s) at 1 meter per second wind speed

2.2 PARAMETRIC STUDIES PERFORMED

The model can calculate the dose at any distance and direction for any desired combination of gamma-ray energy, release height and stability class. The dependence of the exposure rate on these variables was examined in a parametric study that considered a reasonable range of values for each variable. Three energies were chosen for the present study: a low-energy gamma-ray, 80 keV, representative of ^{133}Xe, a medium energy, 250 keV, representative of ^{135}Xe, and a high energy, 1.5 MeV, representative of nuclides such as ^{88}Kr. Three detector circle radii were chosen for examination, 250 m, 500 m, 1000 m. These were considered to be reasonable locations for on-site, site boundary and off-site locations for the detector ring.

Pasquill-Gifford Class A, Class C and Class F atmospheric diffusion conditions were considered. Three release heights were chosen: a ground level, 50 m, and 100 m.

Seven locations were considered for each detector ring. These were chosen with respect to the plume centerline and were at angles 0°, 11.25°, 22.5°, 45°, 90°, 135° and 180°. This choice was made so the study could evaluate the number of detectors required at a given radius and allowed examination of four, eight, sixteen and thirty-two locations on each ring. In addition the choice 11.25° allows examination of the plume centerline half way between two detectors if the ring consists of 16 stations.

A summary description of the parametric calculations performed is given in Table 2.1. Calculations were done for each parameter variation for each of the seven detector angular locations discussed above. This required a total of over 500 calculations.

2.3 RESULTS OF THE PARAMETRIC STUDIES

Representative results of the calculations are given in Appendix B. Plots of the computed exposure rates for a source of 80-keV gamma rays are shown in Figures 2.1 to 2.5. As can be seen from those figures, the shapes of the response curves vary greatly. At a detector radius of 500 m with a ground level release and Class A meteorological conditions (Figure 2.1), the distribution with angle appears nearly Gaussian. However, as can be seen in Figure 2.2 for Class F meteorological conditions, the curve is cusp shaped and the dose rate falls off very rapidly with angle.

Table 2.1

SUMMARY OF PARAMETRIC STUDIES PERFORMED

RADIUS OF DETECTOR RING (METERS)	ATMOSPHERIC STABILITY CLASS	RELEASE HEIGHT (METERS)	ENERGY (keV)
250	A	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500
	C	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500
	F	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500
500	A	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500
	C	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500
	F	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500
1000	A	0	80, 250 & 1500
		100	80, 250 & 1500
	C	50	80, 250 & 1500
	F	0	80, 250 & 1500
		50	80, 250 & 1500
		100	80, 250 & 1500

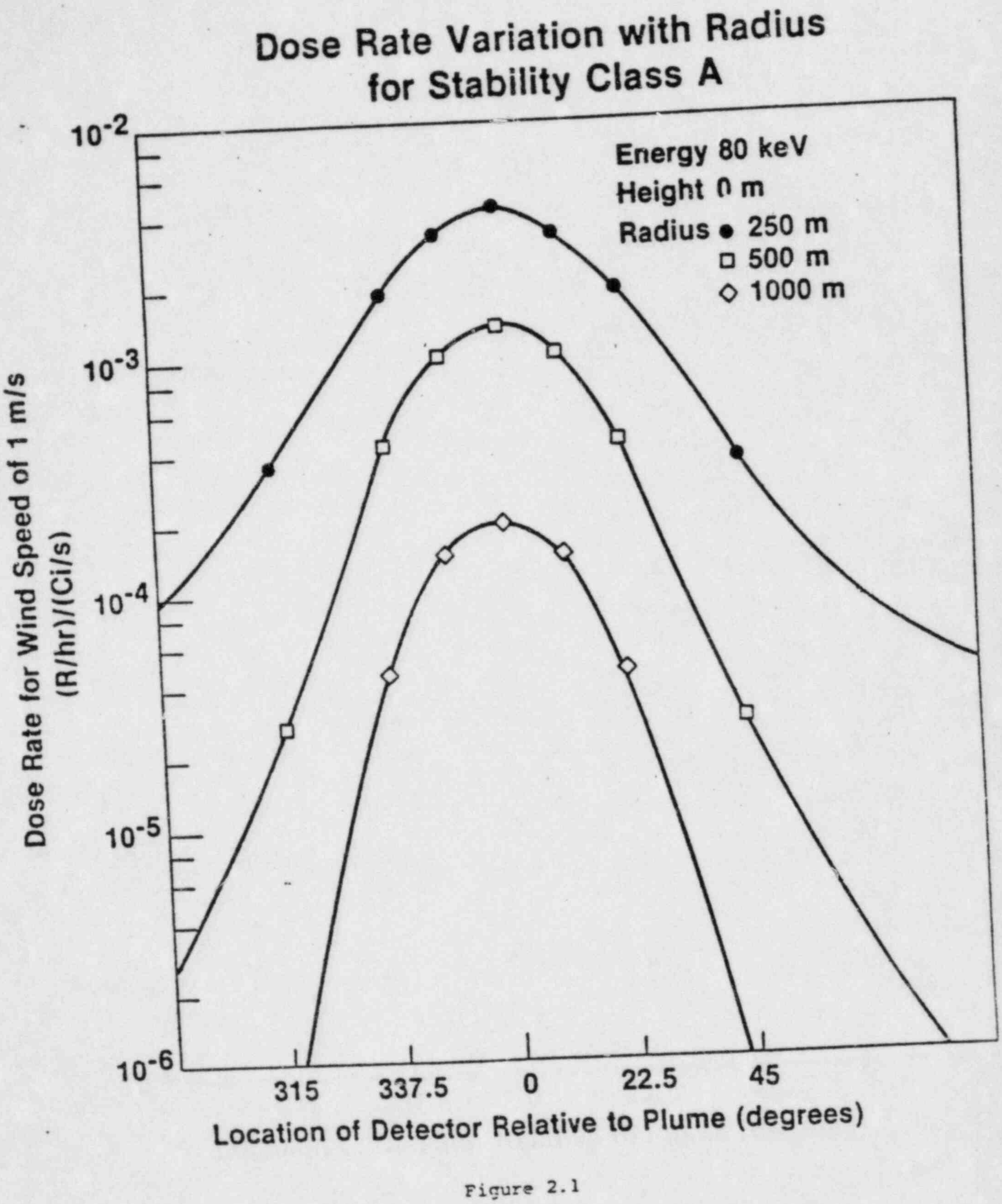

Dose Rate Variation with Radius
for Stability Class A
Energy 80 keV
Height 0 m
Radius ● 250 m
□ 500 m
◇ 1000 m
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Dose Rate for Wind Speed of 1 m/s
(R/hr)/(Ci/s)
315
337.5
0
22.5
45
Location of Detector Relative to Plume (degrees)

Figure 2.1

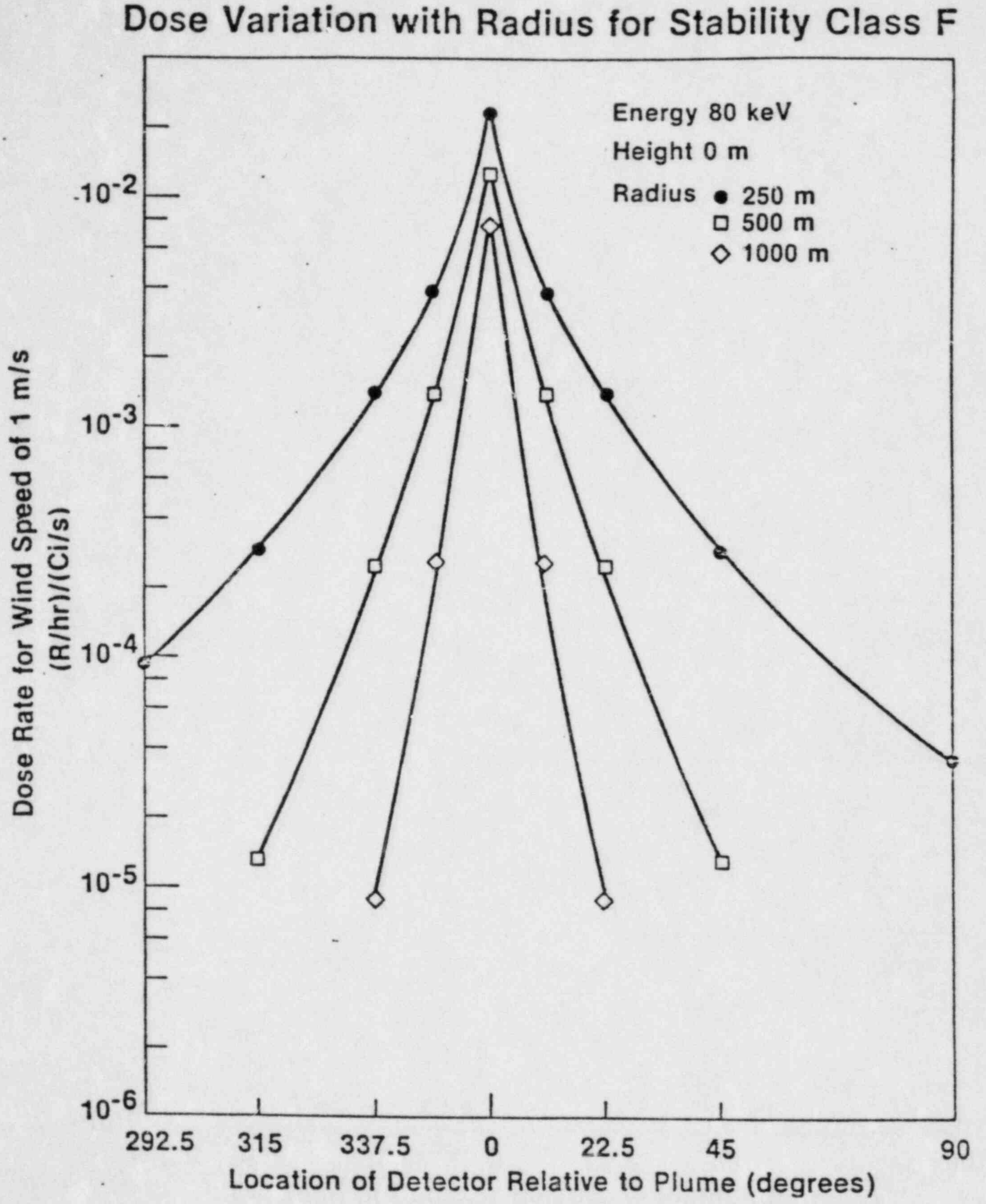

Dose Variation with Radius for Stability Class F
Energy 80 keV
Height 0 m
Radius
250 m
500 m
1000 m
Dose Rate for Wind Speed of 1 m/s
(R/hr)/(Ci/s)
10-2
10-3
10-4
10-5
10-6
292.5
315
337.5
0
22.5
45
90
Location of Detector Relative to Plume (degrees)

Figure 2.2

Dose Rate Variation with Stability Class for Release Height of 0 Meters

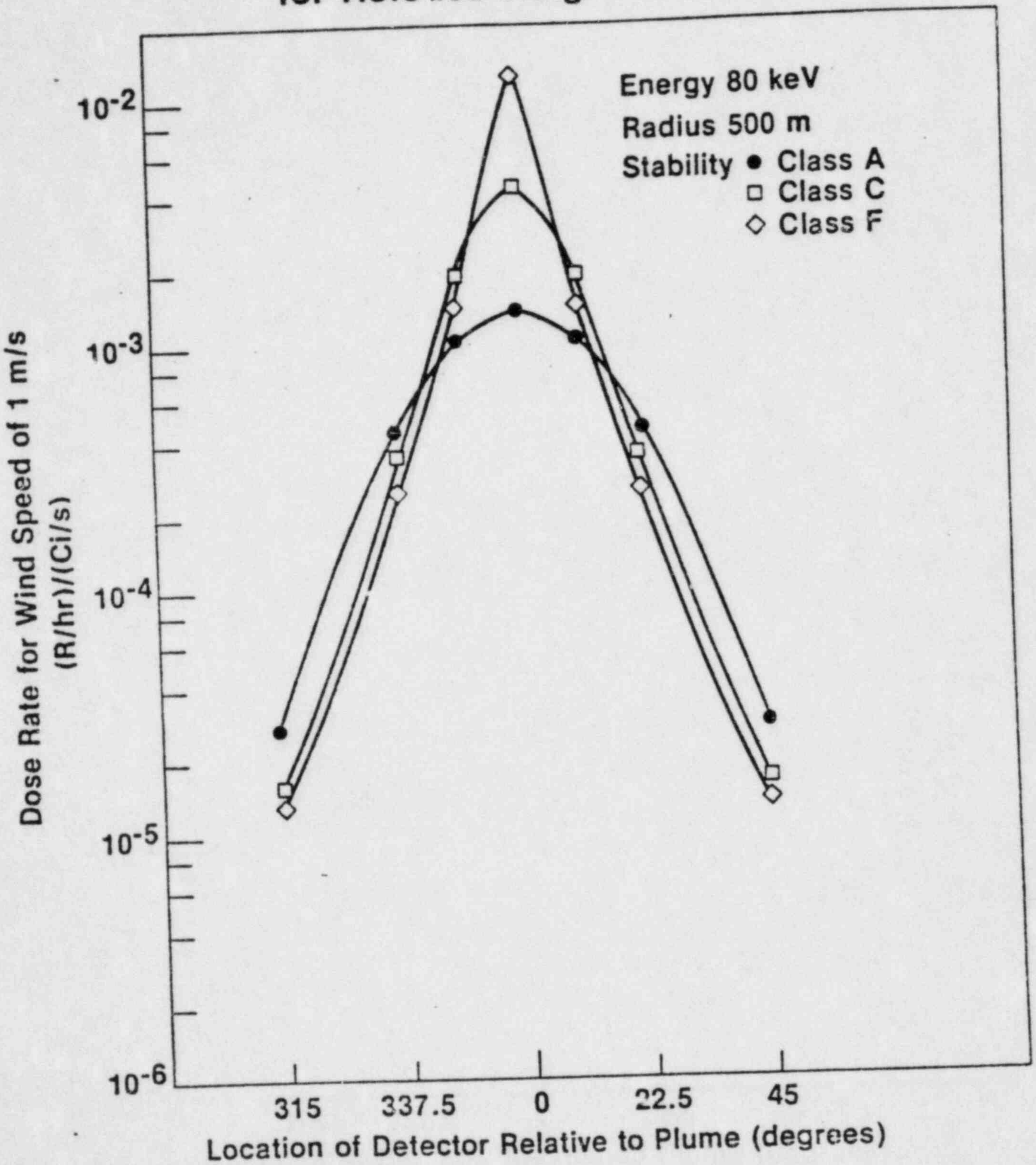


Figure 2.3

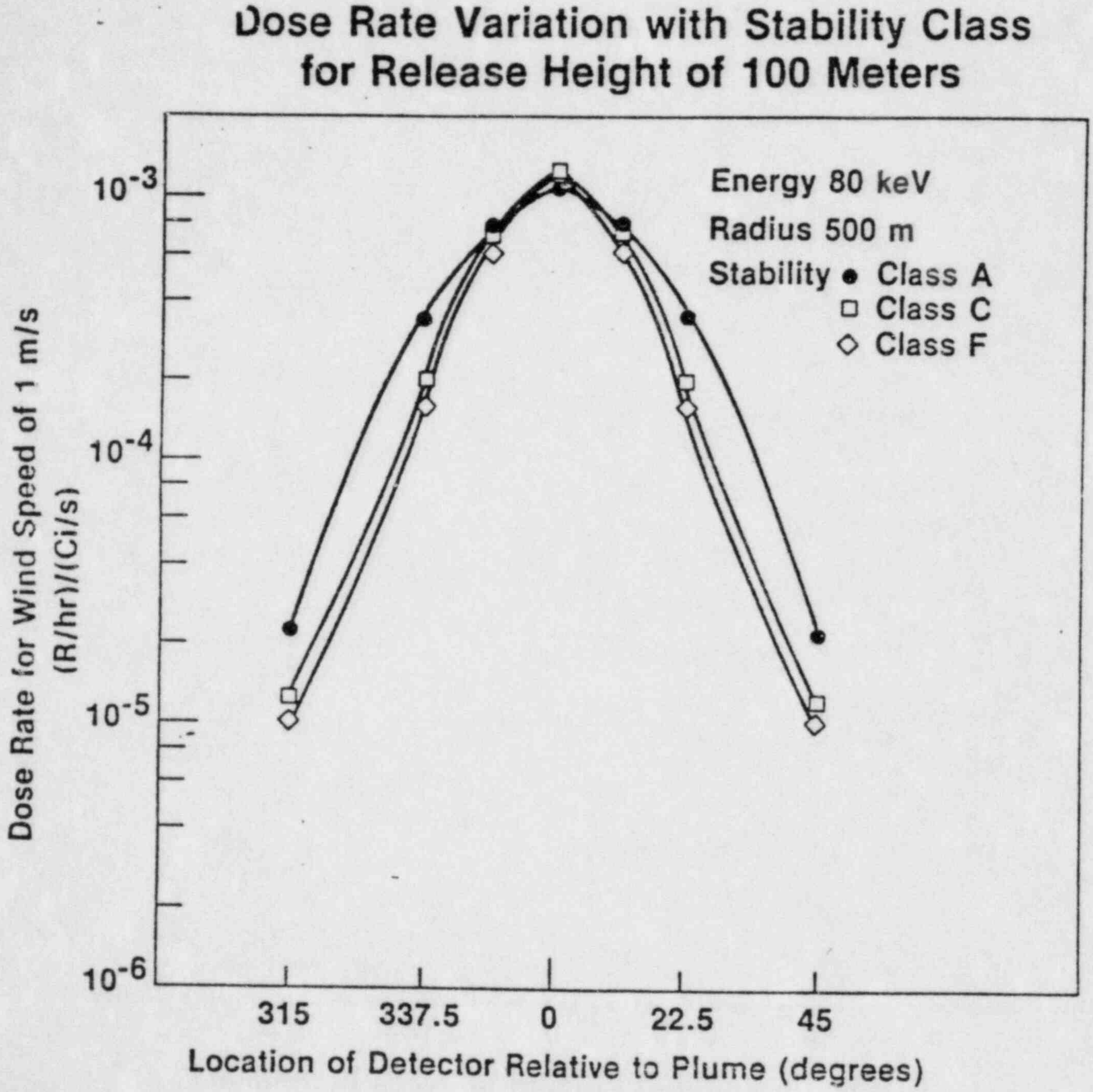

Dose Rate Variation with Stability Class
for Release Height of 100 Meters
Energy 80 keV
Radius 500 m
Stability ● Class A
□ Class C
◇ Class F
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Dose Rate for Wind Speed of 1 m/s
(R/hr)/(Ci/s)
315
337.5
0
22.5
45
Location of Detector Relative to Plume (degrees)

Figure 2.4

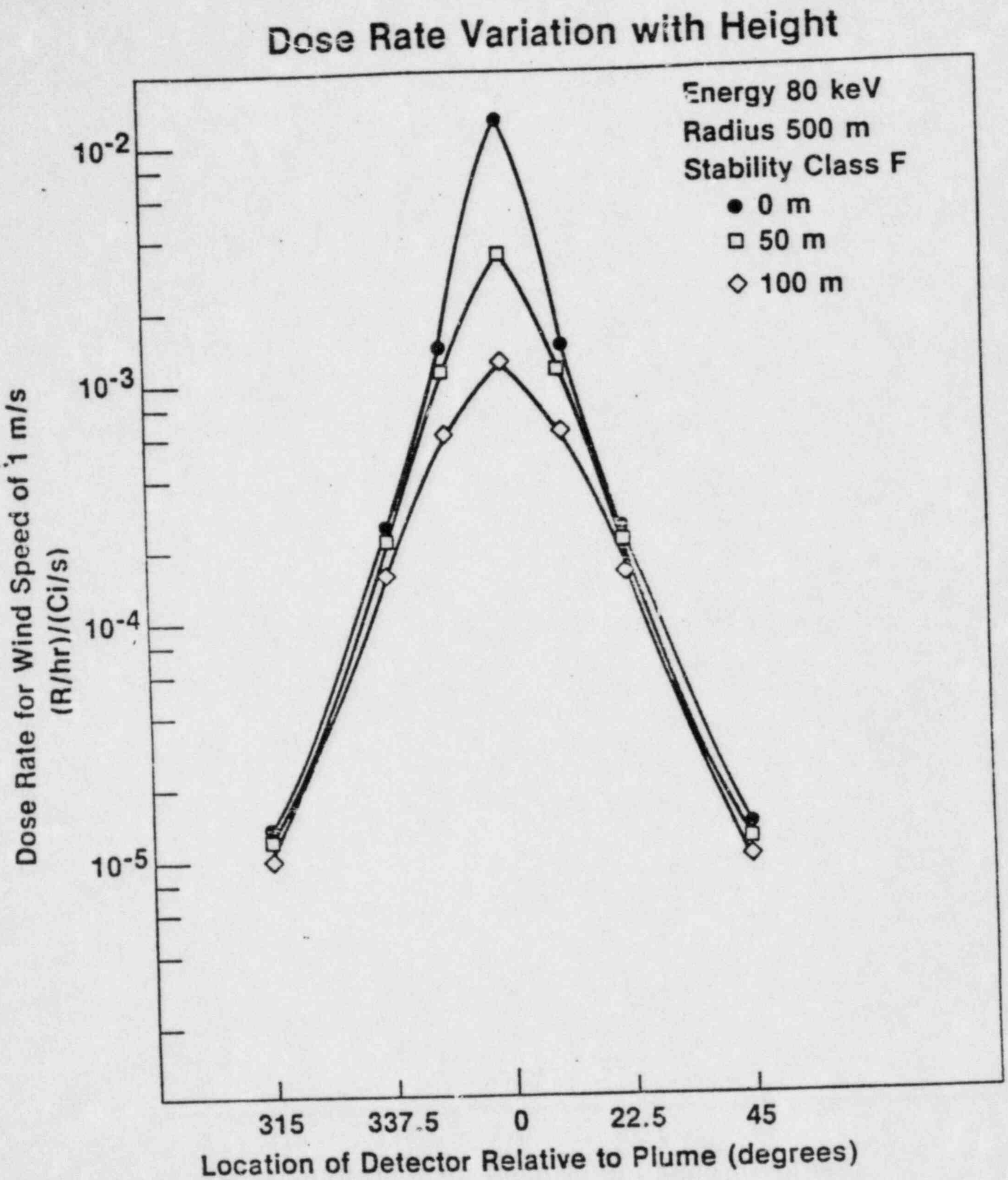

Dose Rate Variation with Height
Energy 80 keV
Radius 500 m
Stability Class F
0 m
50 m
100 m
10-2
10-3
10-4
10-5
Dose Rate for Wind Speed of 1 m/s
(R/hr)/(Ci/s)
315
337.5
0
22.5
45
Location of Detector Relative to Plume (degrees)

Figure 2.5

A limited attempt was made to find a single function that could fit all the distributions resulting from the calculations. Both linear and logarithmic parabolic fits failed to calculate the maximum value within a factor of two accuracy. Two other functional forms were tried. These are

$$\frac{\dot{D}u}{Q} = \frac{A\, e^{-B(\mathrm{Sin}(\theta+\theta_o)}}{\mathrm{Sin}^2(\theta+\theta_o)}, \qquad (7)$$

and

$$\frac{\dot{D}u}{Q} = \mathrm{Exp}(Ae^{-B(\theta)^2}). \qquad (8)$$

The first of these is an approximation to the gamma-ray attenuation and the $1/r^2$ form of dose that describes the Class F conditions reasonably well. The other is a Gaussian in the log of the dose rate that fits Class A releases reasonably well. Neither of these functions provided a satisfactory fit to all of the calculational results.

It is clear that different functional forms are required to obtain the desired interpolation accuracy if the plume does not pass directly over one of the detectors. The hope in finding such a function is that from the response of detectors within about 90° of the plume one might determine the peak value to be expected for the plume centerline at any position between two detectors.

Nonetheless, we can examine the data as plotted to draw conclusions about detector locations. The meteorological stability class has a pronounced effect on the dose rate. This can be clearly seen in Figure 2.3. For a given release rate and wind speed, the centerline dose rate at 500 m may differ by a factor of 10 from Class A to Class F. If the detector ring were at 1000 m this difference would be almost a factor of 50. At 250 m the difference is only a factor of 5.

The effect of the radius of the detector ring can be seen in Figure 2.1 and 2.2. For a Class F condition the dose rate at 250 m would only be about 2-3 times what would be detected at 1000 m. For Class A it would be a factor of about 20.

The effect of release height can be seen in Figure 2.5. For detectors 22.5° degrees or greater off centerline the dose rate is almost the same. The centerline dose rates, however, differ by a factor of about 10.

If the plume centerline passed halfway between two detectors on a ring that had sixteen stations, the dose rate information available would be from locations ± 11.25°, ± 33.75°, ± 56.25°, etc. Figure 2.2 shows the centerline dose rate much greater than a factor of 2 times any measured dose rate. Thus even with sixteen detectors it will be necessary to fit the data from the different stations to obtain the centerline dose rate.

Based on the results of these parametric studies, it appears that with no additional information, data from a ring of sixteen stations would not be adequate to meet the criterion of projecting the true dose rate within a factor of two. Furthermore, because of the strong dependence on stability class and release height, further effort would be required to establish algorithms to estimate dose rates within a factor of two for plumes passing between two stations. The simultaneous availability of station meteorological data would be essential to accomplish this complex task.

Section 3

3.0 ESTIMATED DOSE RATES FOR ACCIDENT CONDITIONS

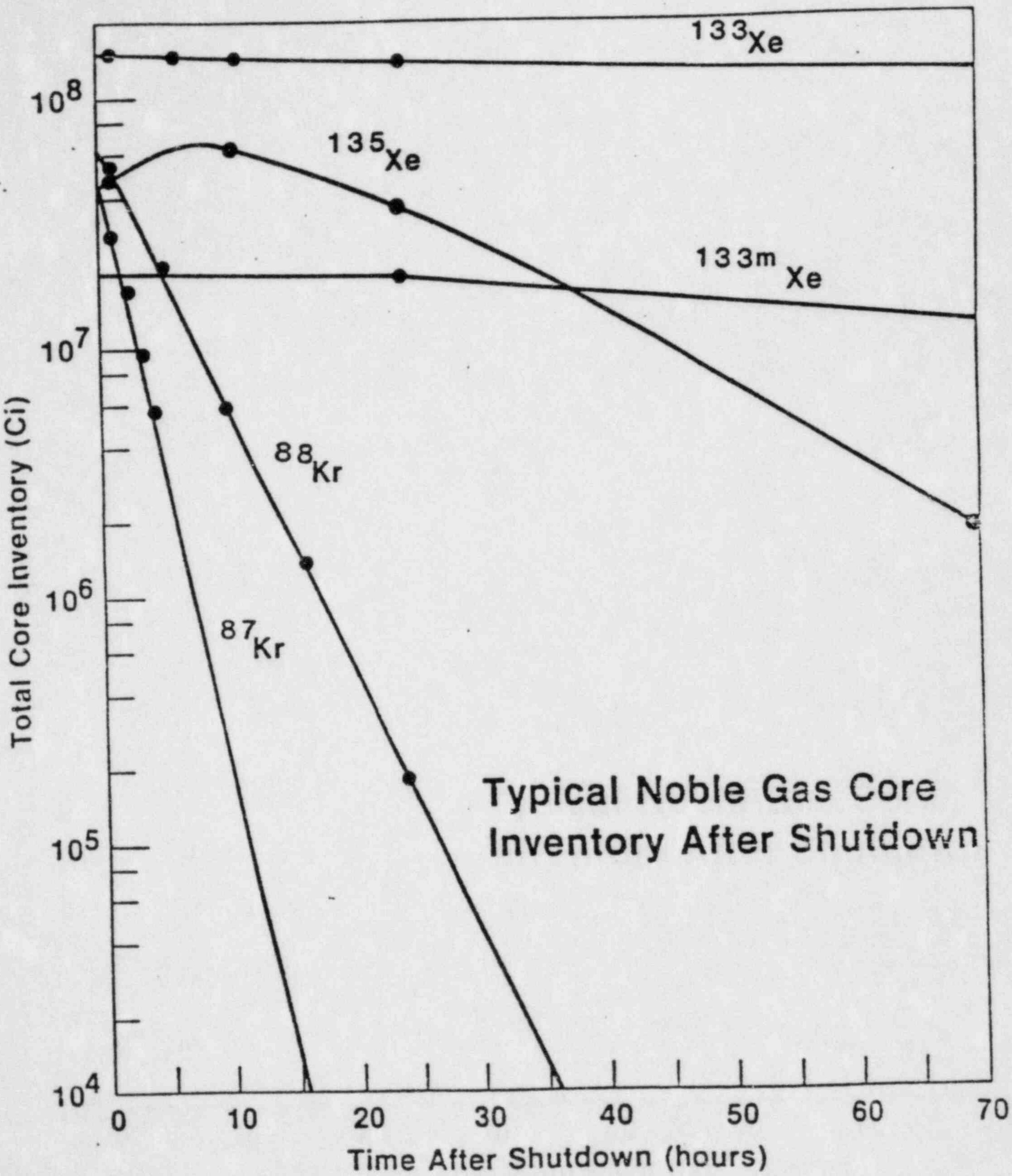
3.1 DESIGN BASIS ACCIDENT

The response of an environs exposure rate monitoring system has been evaluated for a postulated design basis accident. The analysis assumed a direct leak rate from primary containment to the environment of 1% per day. This rate was chosen to simplify scaling to other release rates. In a departure from normal accident assumptions, only the release of noble gases was considered.

3.1.1 Radionuclide Source Term and Estimated Plume Doses

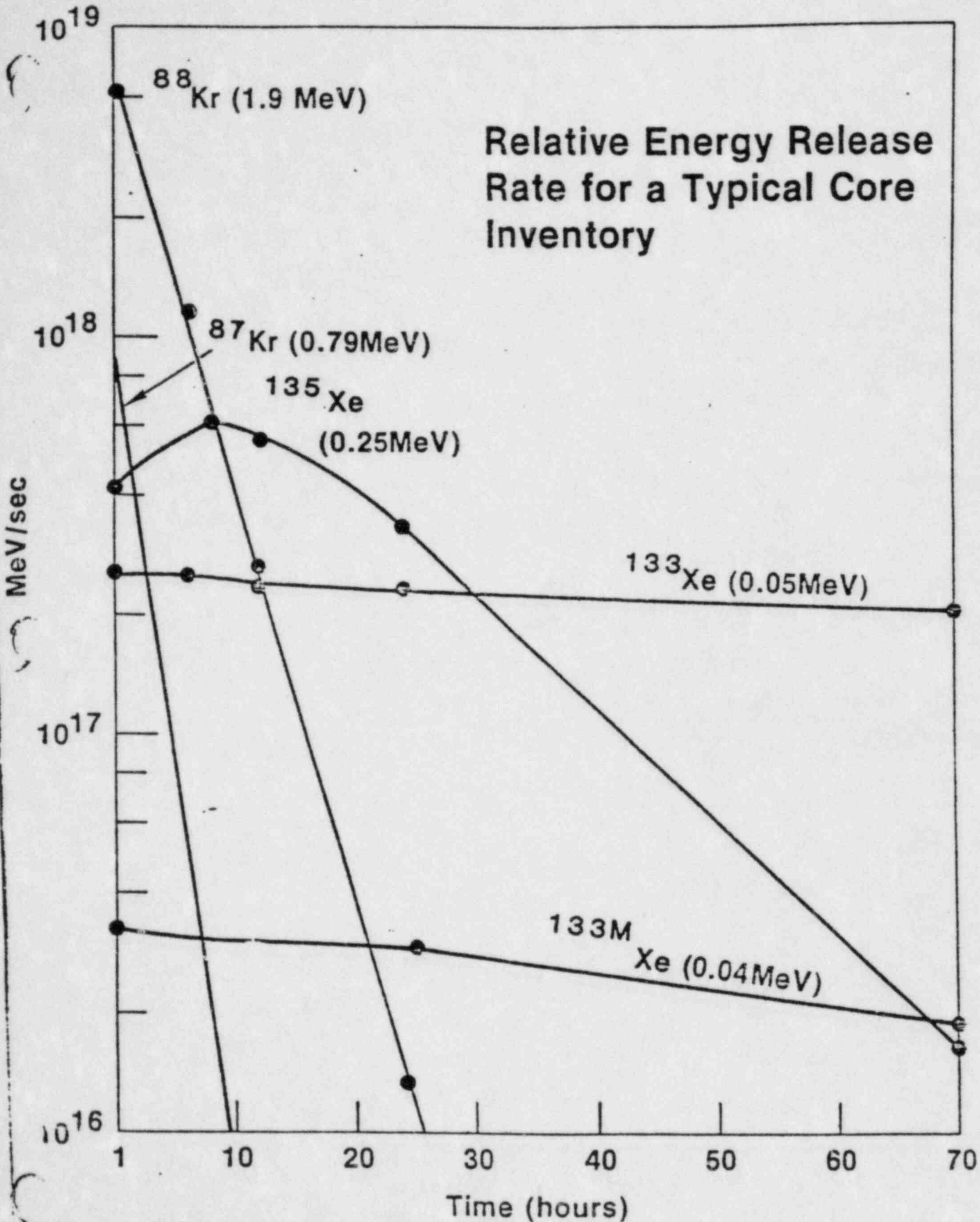
It is necessary to estimate the radionuclide composition and the release rate from the source to estimate the dose rate that will be measured at any detector location. For purposes of this study, only releases of the noble gases have been considered. Although the iodines are a potentially important contribution to the dose rate, experience at TMI indicates a relatively small release of iodines.

To obtain a representative radionuclide release for the present study, we chose the TMI-2 core inventory (3) as being typical. Figure 3.1 shows the total core inventory (Ci) for the major dose contributing nuclides for the first seventy hours following reactor shutdown. Using the average gamma ray energy for each of these nuclides one obtains the relative dose rate contribution (MeV/s) from each nuclide as a function of time. Figure 3.2 shows average gamma ray energies and the energy release rates for a full core inventory. It can reasonably be assumed that the noble gases would all be released at the same rate so the relative contribution to gamma ray source term at any time can be deduced from Figure 3.2.



133Xe
135Xe
133m Xe
88Kr
87Kr
Typical Noble Gas Core Inventory After Shutdown
Total Core Inventory (Ci)
10^8
10^7
10^6
10^5
10^4
0
10
20
30
40
50
60
70
Time After Shutdown (hours)

Figure 3.1



Relative Energy Release Rate for a Typical Core Inventory
^{88}Kr (1.9 MeV)
^{87}Kr (0.79MeV)
^{135}Xe (0.25MeV)
^{133}Xe (0.05MeV)
^{133M}Xe (0.04MeV)
MeV/sec
10^{19}
10^{18}
10^{17}
10^{16}
1
10
20
30
40
50
60
70
Time (hours)

Figure 3.2

It is assumed that 100% of the noble gases escape the core and are available for release to the environment at a rate of 1% per day. Table 3.1 shows the resulting release rate for the important dose contributing nuclides at 1 hour, 12 hours and 24 hours after shutdown. These values are directly proportional to the leak rate and can be adjusted by the ratio of other desired rates to the 1%.

Using this source term, and a typical wind speed of 3 m/s, the dose rate expected for a detector directly under the plume was calculated. Table 3.2 shows these results. The table gives the results for both ground level and 100-meter release points for Class A and Class F stabilities. As can be seen from Table 3.2 at any location and time, the observed dose rate can vary more than an order of magnitude depending on the release point and meteorological condition. This makes interpretation of the data difficult as will be discussed in Section 3.4. The dose rates calculated for the postulated accident are within the range of the detector response (1 μR/hr to 10 R/hr) for detector rings from 250 m to 1000 m.

Table 3.1

RELEASE RATES FOR MAJOR DOSE CONTRIBUTING NOBLE GAS RADIONUCLIDES

Nuclide	Computed Release Rate (Ci/s)[a]		
	T = 1 hr	T = 12 hrs	T = 24 hrs
^{133}Xe	17	17	16
^{135}Xe	5	7	4
^{133m}Xe	2	2	2
^{87}Kr	3	0.01	-
^{88}Kr	6	0.4	0.02
	33.00	26.41	22.02

(a) Assumes 100% noble gas release to containment and leakage to the environment at 1% per day.

TABLE 3.2

CENTERLINE DOSE RATE (mR/hr) FOR 1% PER DAY LEAK RATE AND WIND SPEED OF 3 m/s

	Class A		Class F	
Detector Distance	Ground Level Release	Elevated Release H = 100 m	Ground Level Release	Elevated Release H = 100 m
250 meters				
1 hour	180	52	1100	52
12 hours	42	13	250	13
24 hours	24	7.2	140	7.2
500 meters				
1 hour	61	46	550	53
12 hours	13	11	130	13
24 hours	7.5	6.1	70	7.1
1000 meters				
1 hour	11	12	330	50
12 hours	2.4	2.4	78	12
24 hours	1.3	1.3	44	6.7

3.1.2 Building Shine Dose Rates For a Boiling Water Reactor (BWR)

The radiation field from a Mark I or Mark II BWR reactor building following an accident could be substantial.* A representative dose rate for a design basis accident is shown in Figure 3.3. It was assumed that 100% of the noble gases and 50% of the halogens were released immediately to the containment and subsequently leaked to the reactor building at 1% per day. The noble gases mixed uniformly in the reactor building and were exhausted at a rate of two air changes per day by the standby gas treatment system. The area below the refueling floor was well shielded so that only about 30% of the reactor building activity contributed to the dose rate. This data is presented only to provide an approximation to the building shine contribution. The time of release into the containment and the leak rate into the reactor building can substantially alter the amounts of high energy gamma-rays from short-lived krypton isotopes and change the dose rates appreciably. Figure 3.3 shows the postulated dose rate at 500 meters from the reactor building. The maximum dose rate of 17 mR/hr occurs about eight hours after shutdown. This has been calculated for other distances from the building and is shown in Figure 3.4.

The building shine dose rates can be compared to the calculated plume dose rates shown in Table 3.2. At 500 m and below, dose rates from the unshielded BWR reactor building can approach or exceed centerline dose rates due to a plume. Correction for this shine dose rate may be difficult. The shine may be anisotropic due to building shape and shielding irregularities. Shielding the detectors against reactor building shine would also be difficult. It can be shown that a substantial fraction of the building shine dose rate is due to radiation scattered from the sky above and around the reactor building. Reactor building shine calculations of this type would be required on a site specific basis for establishing a suitable detector ring radius.

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* The secondary containment of a Mark III BWR would not produce a significant shine dose rate following a design basis accident.

Dose Rate at 500 m from a BWR LOCA Source Term in the Reactor Building

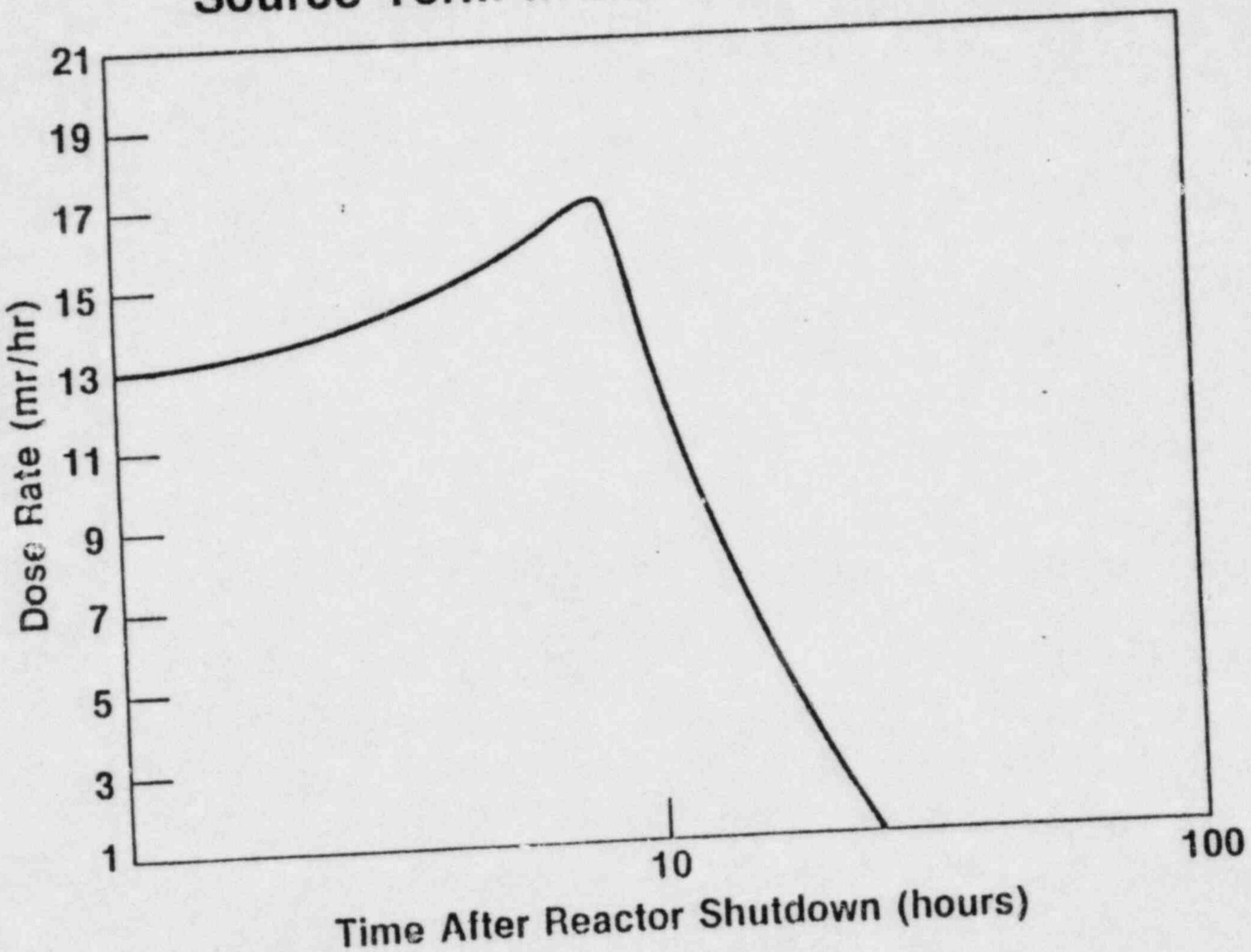


Figure 3.3

Dose Rate From a BWR Reactor Building Eight Hours After a LOCA

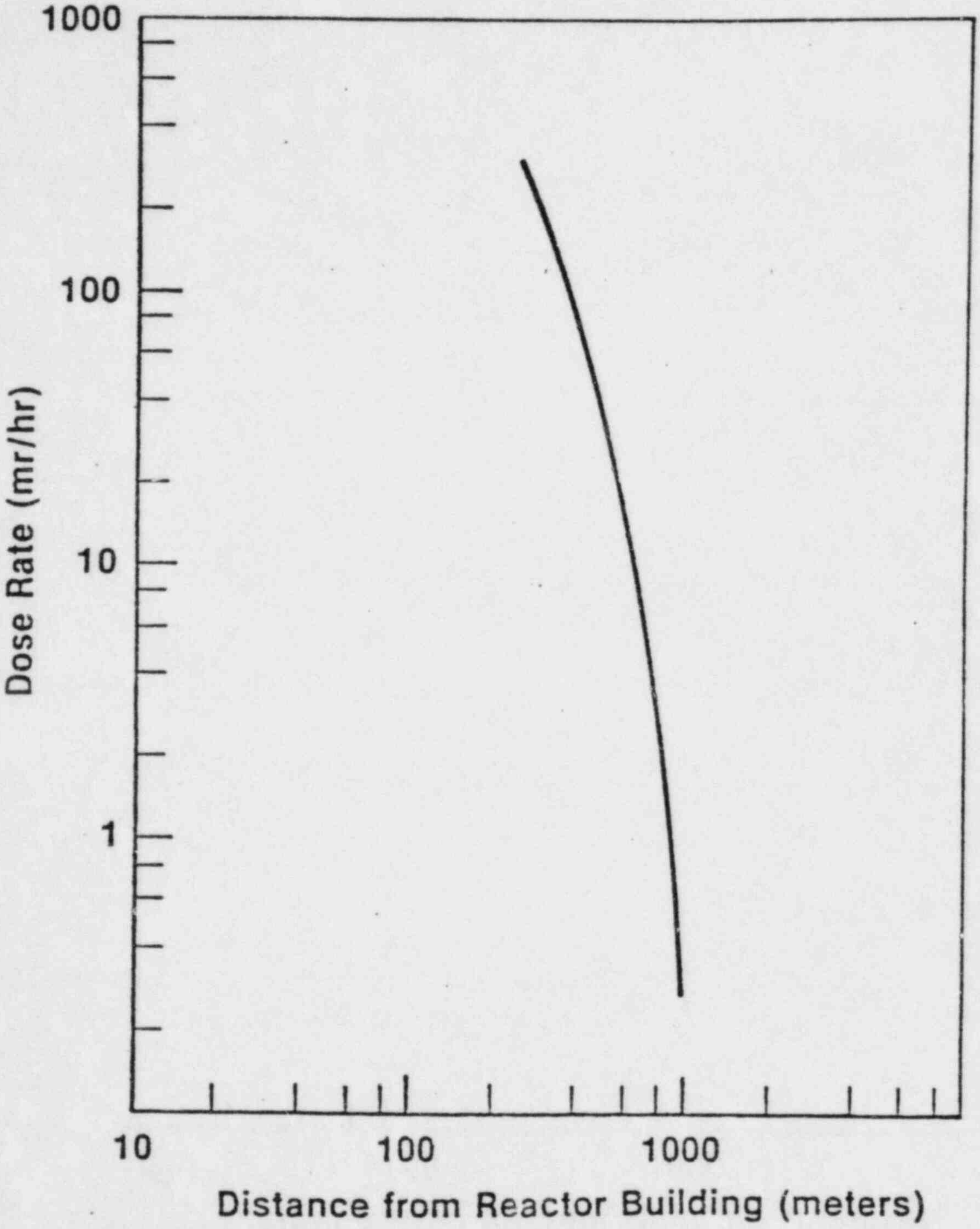


Figure 3.4

3.1.3 Minimum Detectable Release Rates

The response of an environs monitoring system to small ground level releases has been examined to determine the minimum detectable release rate under three different conditions. First with no other release present, second with a design basis accident release and finally with a BWR "shine" component present.

For the first case, with no other release, a criterion was established that a plume passing directly over a monitor should increase its reading by 5 μR/hr. For a plume passing directly between two monitors an increase in both monitors of 2.5 μR/hr should be detectable. This criterion is somewhat arbitrary but such increases should be readily observable. The dose rate was determined for a total release of the entire noble gas core inventory at 1 hour, 12 hours, and 24 hours following shutdown. The minimum detectable release rate was then obtained by taking the fraction of this inventory required to produce the exposure rate of 5 μR/hr for a centerline monitor or 2.5 μR/hr for a plume passing between two monitors. The resulting minimum detectable release rates are shown in Table 3.3 for an assumed wind speed of 3 m/s; these values can be adjusted to other wind speeds by multiplying by the ratio of the desired wind speed to 3 m/s.

Table 3.3 shows that there is a wide variation in release rates that produce the minimum detectable dose rate at the environs monitors. This is because the dose rate at a particular point can be very sensitive to release height and to location of the point relative to the plume centerline.

Table 3.3

MINIMUM DETECTABLE RELEASE RATES WITH NO OTHER IDENTIFIED RELEASES, WIND SPEED OF 3 m/s
(mCi/s)

	Class A				Class F			
	Ground Level Release		Elevated Release H = 100 m		Ground Level Release		Elevated Release H = 100 m	
Detector Distance	Centerline Detector	Off Center Detector	Centerline Detector	Off Center Detector	Centerline Detector	Off Center Detector	Centerline Detector	Off Center Detector
250 m								
1 hour	1	1	3	2	0.2	1	3	2
12 hours	3	3	10	8	0.5	5	10	8
24 hours	5	5	15	13	0.8	7	15	14
500 m								
1 hour	3	3	4	3	0.3	3	3	6
12 hours	10	12	12	15	1	15	10	18
24 hours	15	21	18	24	2	30	15	33
1000 m								
1 hour	16	19	14	20	1	21	3	24
[illegible]2 hours	53	87	53	94	2	127	11	144
[illegible] hours	85	164	85	163	2	333	16	354

The sensitivities in Table 3.3 may be compared with the sensitivity of a typical noble gas radioactivity stack effluent monitor. Typical plant vent stacks have exhaust rates of 100,000 to 500,000 cfm. Monitors with a sensitivity of 10^{-7} μCi/cc are commercially available. For a 500,000 cfm exhaust rate, such a monitor could detect a release rate of 0.02 mCi/cc. Under the most favorable circumstances (Class F ground level release with plume centerline directly over a detector), the environs monitoring system is at best 10 times less sensitive than the stack monitor. In some circumstances (Class F off-center releases), the environs monitoring system can be more than 10,000 times less sensitive than the stack monitor. For a 100,000 cfm stack exhaust rate, the environs monitoring system would be 50 to 50,000 times less sensitive than the stack monitor for the conditions of Table 3.3.

The exposure rates resulting from a design basis accident release are given in Table 3.2. The criterion chosen for an additional ground level release to be detectable was that the monitor reading increase by one third.* Thus, for Class A meteorology, at 1 hour a monitor at 250 m would have to increase from 180 mR/hr to 239 mR/hr. Based on this criterion the minimum detectable additional release rates for a centerline station are given in Table 3.4.

The same criterion was used for the minimum detectable limit in the presence of a BWR shine component, i.e., the monitor should increase by a factor of one third. The dose rate contribution from shine and the minimum detectable ground level release rate are given in Table 3.5.

* Results presented later (in Sections 3.2 and 3.3) suggest that this criterion may be somewhat optimistic due to the effects of meteorological fluctuations. Such fluctuations can cause a monitor reading to change by a factor of 10 without a significant change in release rate.

Table 3.4

MINIMUM DETECTABLE GROUND LEVEL RELEASE CONCURRENT*
WITH DESIGN BASIS ACCIDENT RELEASE, CENTERLINE STATION
(mCi/s)

	Class A		Class F	
Detector Distance	Normal Ground Level Release	Normal Elevated Release H = 100 m	Normal Ground Level Release	Normal Elevated Release H = 100 m
250 meters				
1 hour	11000	3200	11000	520
12 hours	8700	2700	8700	450
24 hours	7300	2200	7300	370
500 meters				
1 hour	11000	8200	11000	1100
12 hours	8700	7400	8700	870
24 hours	7300	5900	7300	740
1000 meters				
1 hour	11000	12000	11000	1700
12 hours	8700	8700	8700	1300
24 hours	7300	7300	7300	1100

* These results are based on the "1/3 increase" criterion, which may be optimistic. See footnote on page 3-12.

Table 3.5

MINIMUM DETECTABLE GROUND LEVEL RELEASE*
WITH THE PRESENCE OF BWR SHINE
(mCi/s)

Detector Distance	BWR Shine Dose Rate (mR/hr)	Minimum Detectable Limit Class A (mCi/s)	Minimum Detectable Limit Class F (mCi/s)
250 meters			
1 hour	180	11000	1800
12 hours	184	38000	6400
24 hours	67	20000	3500
500 meters			
1 hour	13	2300	260
12 hours	9.6	6400	640
24 hours	1.4	1400	150
1000 meters			
1 hour	0.22	220	10
12 hours	0.15	540	20
24 hours	0.02	110	3

* These results are based on the "1/3 increase" criterion, which may be optimistic. See footnote on page 3-12.

3.2 ANALYSIS OF A HYPOTHETICAL ENVIRONS MONITORING SYSTEM AT THREE MILE ISLAND

The meteorology and estimated radionuclide release rates for the TMI-2 accident were used to estimate the performance of an environs monitoring system had one been installed. The hypothetical system consisted of a ring of sixteen equally spaced stations at a radius of 1000 meters. The assumed ring is shown in Figure 3.5. The stations are numbered one through sixteen, clockwise, with station #1 located $+11.5^{\circ}$ from north. This particular arrangement was chosen because only one station (#10) would be located on the river.

The response of the monitoring system was evaluated for two six hour time periods. The first period was from 0700 until 1300 on March 28, 1979, when the first releases occurred from the plant. The second period was from 2000 on March 28 until 0200 March 29 and included the period of maximum releases. It was assumed that all releases occurred at an elevation of 25 m.

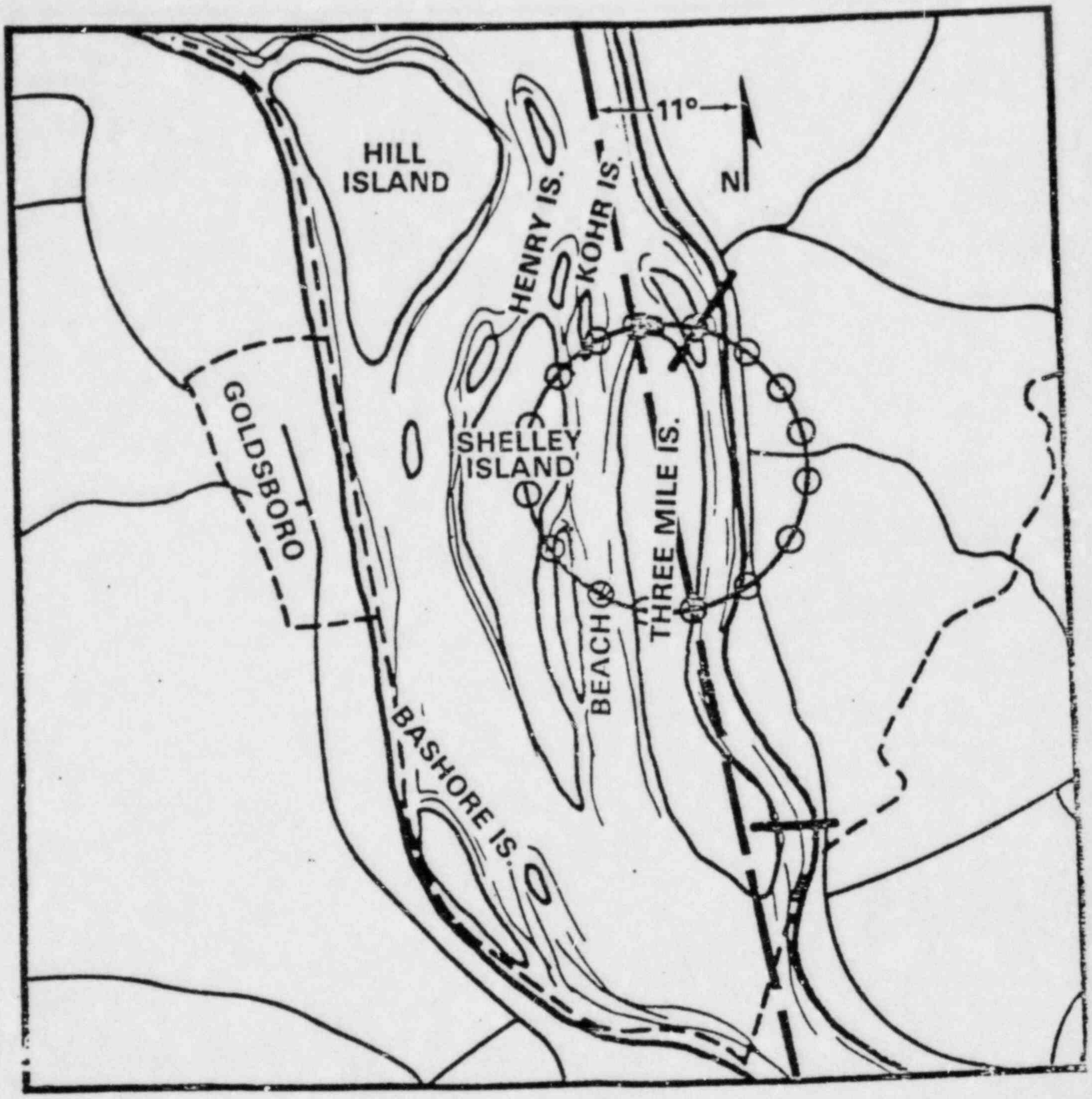
3.2.1 Radionuclide Release Rates

The release rates were obtained from the Assessment of Offsite Doses From The Three Mile Island Unit 2 Accident, TDR-TMI-116 (4). This data is reproduced in Appendix D. There were some adjustments made to the data as presented. Due to the low contribution to the dose rate from ^{133m}Xe, it was not included in the evaluation. However, ^{87}Kr was included because of its relatively high energy gamma radiation. The data from Appendix D were used to estimate average release rates for 15-minute pe[illegible] in order to correspond with the reported meteorological data.

Because of the short half lives of ^{87}Kr, ^{88}Kr and ^{135m}Xe, the data from Appendix D was corrected for decay for the early time period. The average release rate of ^{88}Kr from 0700 until 0900 is reported as 5.5×10^3 µCi/sec. The release rate used was 7.8×10^3 µCi/sec at 0700 and decreased to 3.9×10^3 µCi/sec at 1000. This produced an average release rate of 5.5×10^3 µCi/sec for the three hour period. ^{135m}Xe was treated in a similar manner. The ratio of ^{87}Kr to ^{88}Kr in the TMI-2 core inventory at 0700 was 0.29 (4). The release rate for ^{87}Kr was assumed to be $0.29 \times 7.8 \times 10^3$ µCi/sec at 0700

Figure 3.5

HYPOTHETICAL LOCATION OF MONITORING STATIONS FOR TMI



and it was also decayed. The release rates used for this study are shown in Tables 3.6 and 3.7.

3.2.2 Meteorology

The 15-minute average raw meteorological data was obtained from Pickard, Lowe and Garrick for the first day of the accident at TMI-2.

Tables 3.8 and 3.9 give the meteorological parameters used for the two different time periods. Also listed in these tables are the hypothetical station identifications for the monitor nearest the plume centerline and the deviation of plume centerline from the nearest station. For a zero degree deviation the plume would pass directly over a monitor.

During the first period of releases, meteorological conditions were mostly neutral (Class D) or extremely unstable (Class A) with one 15-minute period of slightly unstable (Class C). During the six hour period the wind direction was quite variable and blew in the direction of almost every station for some period.

During the second period when the highest releases occurred, conditions were slightly stable (Class E) for the entire period. The wind speed did not change greatly and was blowing in the direction of Station 15 (~NW) most of the time.

3.2.3 Calculated Dose Rates

Using the meteorological parameters and the release rates, the dose rates were calculated for each fifteen minute period from 0700-1300 and from 2000-0200. Since the meteorological data was available only for fifteen minute intervals, the dose rates were considered to be constant during each interval. Plume meander and changing wind speeds during each interval could not be considered.

3.2.3.1 Period of First Releases

The dose rates that would be measured at each hypothetical station during this period are shown in Table 3.10. A background reading of 7 μR/hr was

Table 3.6

ADJUSTED NOBLE GAS RELEASE RATES AT TMI-2 FROM
0700 UNTIL 1300 MARCH 28, 1979
(Ci/sec)

Time	^{87}Kr	^{88}Kr	^{133}Xe	^{135}Xe	^{135m}Xe	Total
0700	2.2-03*	7.8-03	9.8-02	1.0-02	4.7-03	0.123
0715	2.0-03	7.3-03	9.8-02	1.0-02	4.6-03	0.122
0730	1.7-03	6.9-03	9.8-02	1.0-02	4.5-03	0.121
0745	1.5-03	6.5-03	9.8-02	1.0-02	4.3-03	0.120
0800	1.3-03	6.1-03	9.8-02	1.0-02	4.2-03	0.120
0815	1.1-03	5.7-03	9.8-02	1.0-02	4.1-03	0.119
0830	9.9-04	5.4-03	9.8-02	1.0-02	4.0-03	0.118
0845	8.7-04	5.1-03	9.8-02	1.0-02	3.9-03	0.118
0900	7.6-04	4.7-03	9.8-02	1.0-02	3.8-03	0.117
0915	6.6-04	4.5-03	9.8-02	1.0-02	3.7-03	0.117
0930	5.8-04	4.2-03	9.8-02	1.0-02	3.6-03	0.116
0945	5.0-04	3.9-03	9.8-02	1.0-02	3.5-03	0.116
1000	3.9-02	3.3-01	5.8	0.9	2.9-01	7.4
1015	3.4-02	3.1-01	5.8	0.9	2.8-01	7.3
1030	3.0-02	2.9-01	5.8	0.9	2.7-01	7.3
1045	2.6-02	2.8-01	5.8	0.9	2.7-01	7.28
1100	2.3-02	2.6-01	5.8	0.9	2.6-01	7.24
1115	2.0-01	2.5-01	5.8	0.9	2.5-01	7.22
1130	1.7-02	2.3-01	5.8	0.9	2.5-01	7.20
1145	1.5-02	2.2-01	5.8	0.9	2.4-01	7.2
1200	1.7-02	2.6-01	7.4	1.2	2.9-01	9.2
1215	1.5-02	2.5-01	7.4	1.2	2.8-01	9.15
1230	1.3-02	2.3-01	7.4	1.2	2.7-01	9.11
1245	1.1-02	2.2-01	7.4	1.2	2.7-01	9.10

* 2.2-03 means 2.2×10^{-3}.

Table 3.7

ADJUSTED NOBLE GAS RELEASE RATES AT TMI-2 FROM
2000 28 MARCH 1979 UNTIL 0200 29 MARCH 1979
(Ci/sec)

Time	^{87}Kr	^{88}Kr	^{133}Xe	^{135}Xe	^{135}[illegible]	Total
2000	6.4-04*	0.15	16	5.4	0.49	22
2015	6.4-04	0.15	16	5.4	0.49	22
2030	6.4-04	0.15	16	5.4	0.49	22
2045	6.4-04	0.15	16	5.4	0.49	22
2100	1.6-03	0.38	52	17	1.4	71
2115	1.6-03	0.38	52	17	1.4	71
2130	1.6-03	0.38	52	17	1.4	71
2145	1.6-03	0.38	52	17	1.4	71
2200	2.7-03	0.63	110	34	2.7	147
2215	2.7-03	0.63	110	34	2.7	147
2230	2.7-03	0.63	110	34	2.7	147
2245	2.7-03	0.63	110	34	2.7	147
2300	1.4-03	0.32	180	25	1.8	207
2215	1.4-03	0.32	180	25	1.8	207
2230	1.4-03	0.32	180	25	1.8	207
2245	1.4-03	0.32	180	25	1.8	207
2400	1.4-03	0.32	180	25	1.8	207
0015	1.4-03	0.32	180	25	1.8	207
0030	1.4-03	0.32	180	25	1.8	207
0045	1.4-03	0.32	180	25	1.8	207
0100	1.5-04	3.5-02	32	43	0.25	37
0115	1.5-04	3.5-02	32	43	0.25	37
0130	1.5-04	3.5-02	32	43	0.25	37
0145	1.5-04	3.5-02	32	43	0.25	37

* 6.4-04 means 6.4×10^{-4}.

Table 3.8

METEOROLOGICAL PARAMETERS FOR TMI-2
0700 TO 1400
28 MARCH 1979

Time	Pasquill-Gifford Stability Class	Wind Speed (m/s)	Direction[(1)] (degrees)	Centerline Station	Deviation From Centerline (degrees)
0700	D	1.3	81	12	2
0715	D	0.8	101	12	0
0730	D	2.0	90	12-13	11
0745	D	2.6	69	12	-10
0800	D	2.8	64	11	8
0815	D	3.1	79	12	0
0830	D	1.9	65	11	9
0845	D	2.1	90	12-13	11
0900	C	1.3	171	16	2
0915	A	1.2	3	9	-8
0930	D	1.3	168	16	-1
0945	D	1.8	225	2-3	11
1000	A	2.1	237	3	0
1015	D	1.3	203	1-2	11
1030	D	1.4	317	7	-9
1045	A	1.6	289	5	8
1100	A	1.8	272	5	-9
1115	A	1.7	259	4	0
1130	A	1.9	247	3-4	11
1145	D	2.3	159	16	-10
1200	A	2.1	178	16	9
1215	D	2.1	162	16	-7
1230	D	2.6	164	16	-5
1245	A	2.1	205	2	-9
:					

(1) Wind from ... degrees.

Table 3.9

METEOROLOGICAL PARAMETERS FOR TMI-2
2000 28 MARCH 1979 TO 0200 29 MARCH 1979

Time	Pasquill-Gifford Stability Class	Wind Speed (m/s)	Direction[1] (degrees)	Centerline Station	Deviation from Centerline Station (degrees)
2000	E	3.4	138	15	-8
2015	E	3.4	137	15	-9
2030	E	3.1	143	15	-3
2045	E	3.3	145	15	0
2100	E	3.2	149	15	3
2115	E	3.6	152	15	5
[illegible]130	E	4.0	150	15	3
2145	E	3.6	150	15	3
2200	E	3.8	157	15	11
2215	E	4.2	147	15	0.5
2230	E	3.8	146	15	-0.5
2245	E	3.5	152	15	5
2300	E	4.0	155	15	8
2315	E	3.8	146	15	-0.5
2330	E	4.0	146	15	-0.5
2345	E	3.4	138	15	-8
2400	E	3.5	157	15	10
0015	E	2.6	176	16	7
0030	E	3.1	191	1	0
0045	E	2.5	173	16	4
0100	E	2.4	169	16	0
0115	E	3.2	155	15	8
0130	E	3.0	124	14	0
0145	E	1.9	113	13-14	11

(1) Wind from.....degrees.

assumed (4) for each station and only readings above this estimated background are given in Table 3.10. Also shown in this table are the maximum dose rates that would occur directly under the plume centerline and the ratio of the dose rate at the maximum station to the dose rate directly under the plume centerline.

During the period from 0700 until 1000 hours, the release rate was quite low and only two or three stations would have registered above background. The effects of wind speed and direction are quite apparent if the dose rate at 0715 is compared to the reading at 0730. Although the release rate is essentially the same, the wind was blowing directly at station 12 at 0715 and in between 12 and 13 at 0730. The resulting dose rate at 0715 was 660 μR/hr and at 0730, 28 μR/hr a factor greater than 20. The release rate increased at 1000 hours and is reflected in the number of stations reading above background as well as the general increase in the maximum station reading. The maximum station reading along with the dose directly under the plume is plotted in Figure 3.6.

3.2.3.2 Periods of Maximum Releases

Table 3.11 shows the dose rates that would have occurred during the period of maximum releases at TMI-2. Only stations 1,2,3,12,13,14,15 and 16 would have shown readings above background during this period. The wind direction and speed were more nearly constant during this period and directed toward station Number 15 most of the time. The Pasquill-Gifford stability was Class E for the entire period resulting in a narrow plume. As would be expected for the Class E condition, the deviation of the maximum station reading from the plume centerline was more pronounced. This can be clearly seen in Figure 3.7. It should be noted that the large differences between the dose rate directly under the plume and the dose rate at the maximum station that occur at 2200, 2400 and 0145 were when the plume passed halfway between stations. If the number of stations had been doubled so that there were 32 stations on the ring, one of these stations would have been directly under the plume.

3.2.4 Conclusions

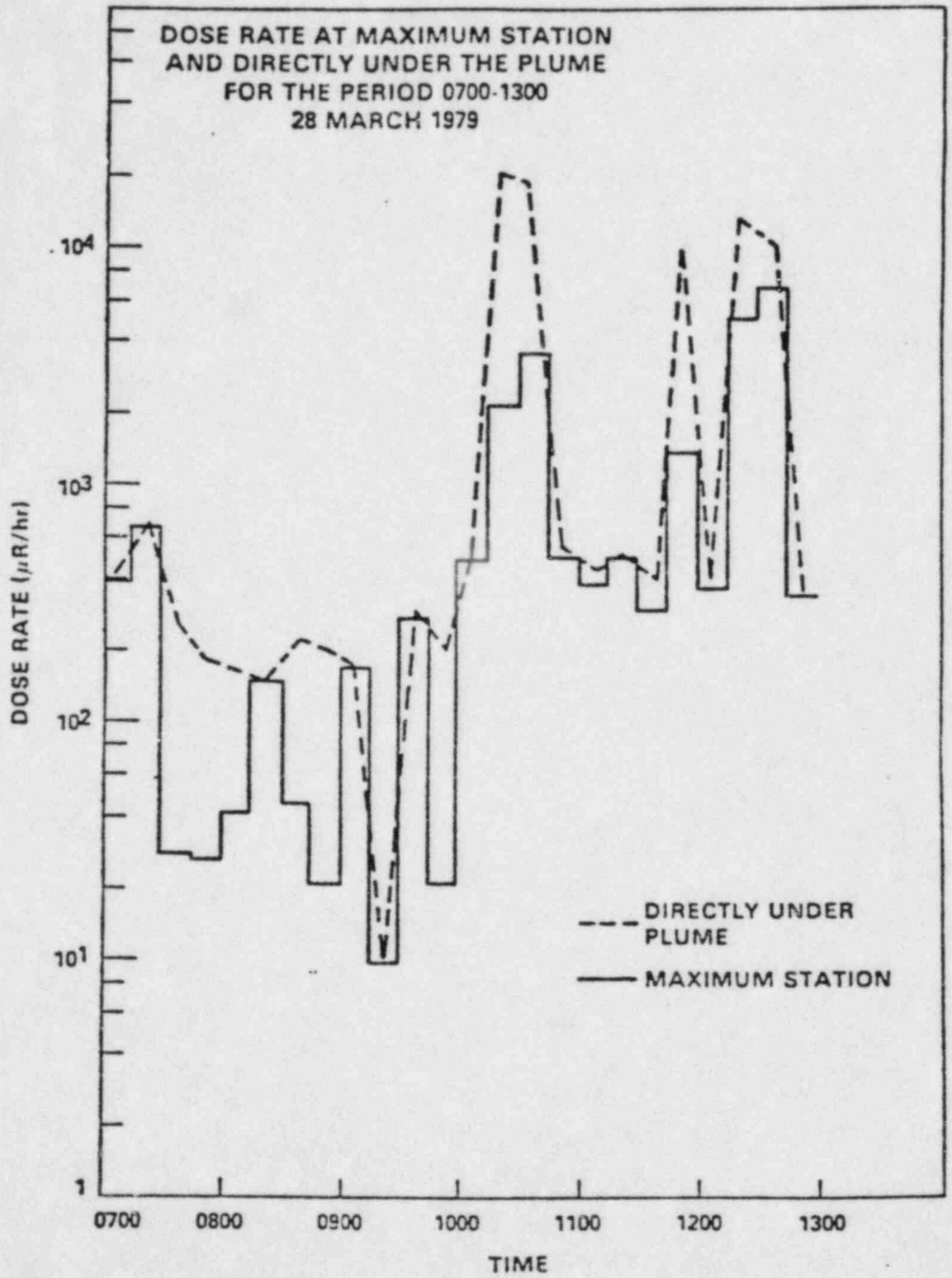
This analysis of a hypothetical monitoring system applied to the TMI-2 accident conditions generally supports and reinforces the conclusions of the ideal model studies performed in Section 2. Even for periods of constant release rate and relatively unchanging meteorological conditions, the dose rate at the maximum station can vary as much as a factor of 10. The results presented in Figures 3.6 and 3.7 clearly demonstrate the need for an algorithm to estimate dose rates from plumes passing between two detectors.

Table 3.10

DOSE RATES ABOVE NATURAL BACKGROUND AT HYPOTHETICAL MONITORING STATIONS AROUND TMI-2 FOR THE PERIOD 0700 TO 1300 28 MARCH 1979 (μR/hr)

Time	Station Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Maximum Plume Centerline	Ratio Maximum Station / Plume Centerline
0700											5.2	390.	7.5				423	.9
0715												9.3	660.	9.3			660	1.0
0730												28.	28.				253	0.1
0745											16.	27.					187	0.1
0800											42.	8.4					167	0.1
0815											1.9	150.	1.9				150	[illegible].0
0830											46.	12.0					229	.1
0845												21.	21.				201	.1
0900	8.0														3.0	170.	171	.9
0915								6.7	9.8	2.1							12	.8
0930	4.0														2.5	280.	294	1.0
0945		21.	21.														205	.1
1000	20.	150.	490.	150.	20.	3.6										3.6	490	1.0
1015	2200.	2200.	58.	8.2											5.2	58.	20600	0.1
1030				4.8	34.	1300.	3700.	75.	5.6								18500	0.2
1045			2.3	66.	500.	400.	44.	7.									559	.9
1100		6.1	36.	320.	390.	59.	7.										474	.8
1115	3.4	19.	150.	500.	150.	19.	1.4										500	1.0
1130	6.2	39.	300.	300.	39.	6.2											418	.7
1145	640.	150.	2.5												28.	1400.	9940	.1
1200	280.	33.												7.5	50.	380.	415	.9
1215	470.	16.												4.8	52.	5000.	13300	.4
1230	230.	9.8												4.5	50.	6900.	10400	.7
1245	270.	350.	48.	6.3											4.2	23.	412	.8

Figure 3.6



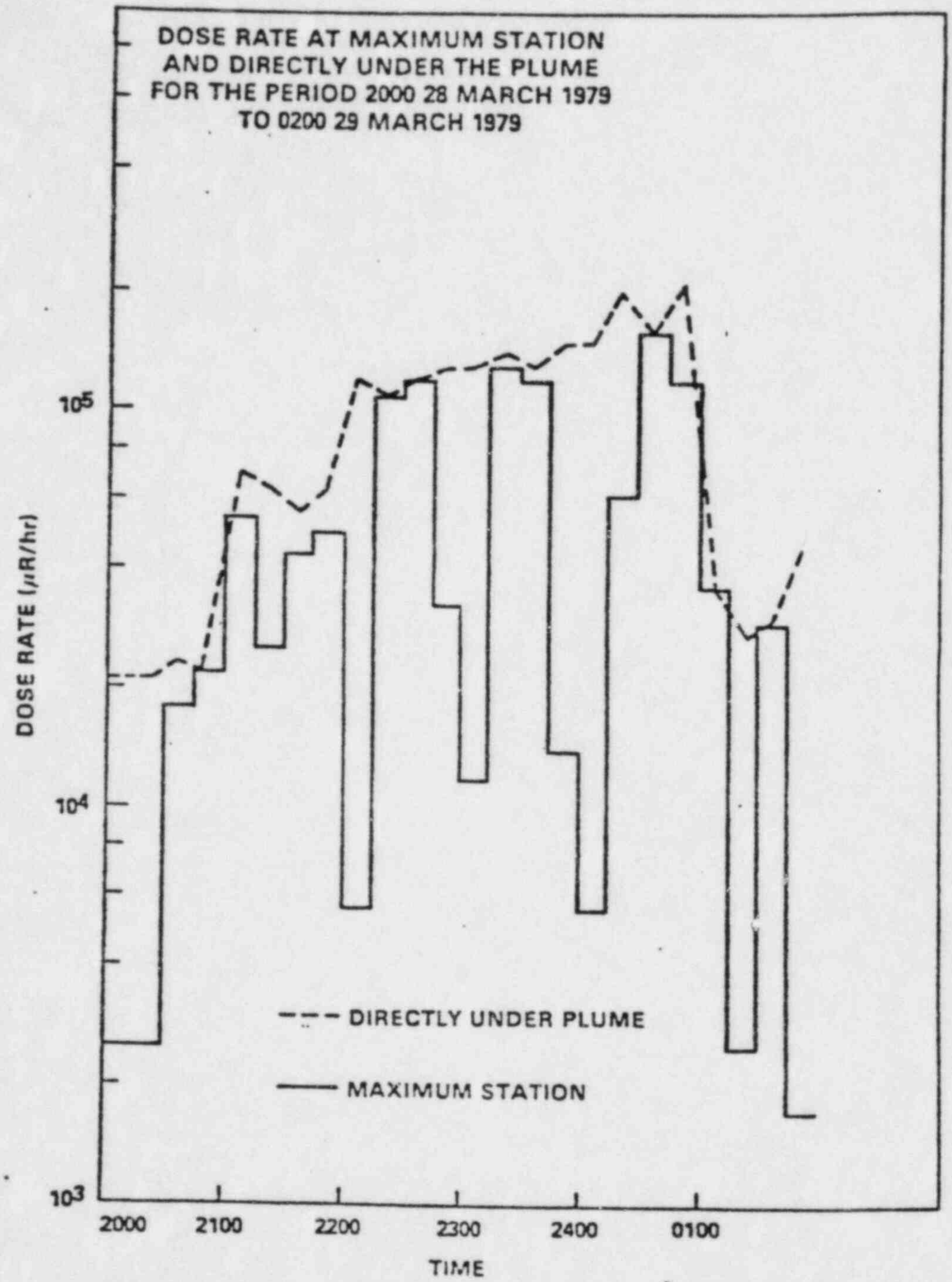
DOSE RATE AT MAXIMUM STATION
AND DIRECTLY UNDER THE PLUME
FOR THE PERIOD 0700-1300
28 MARCH 1979
DOSE RATE (μR/hr)
10^4
10^3
10^2
10^1
1
0700
0800
0900
1000
1100
1200
1300
TIME
DIRECTLY UNDER PLUME
MAXIMUM STATION

Table 3.11

DOSE RATES ABOVE NATURAL BACKGROUND AT HYPOTHETICAL MONITORING STATIONS AROUND TMI-2 FOR THE PERIOD 2000 28 MARCH 1979 TO 0200 29 MARCH 1979 (μR/hr)

Time	Station Number 12	13	14	15	16	1	2	3	Maximum Plume Centerline	Ratio Maximum Station / Plume Centerline
2000		11	490	2500	18				21000	0.1
2015		11	490	2500	18				21000	0.1
2030		6.6	130	18000	47				23000	0.8
2045		4.8	74	22000	74	4.8			22000	1.0
2100		8.5	120	55000	400	16			70000	0.8
2115		6.4	70	25000	620	18			63000	0.4
2130		6.8	96	44000	320	13			56000	0.8
2145		7.6	110	49000	360	17			63000	0.8
2200		5.9	47	5600	5600	47	5.9		120000	0.04
2215		16	300	110000	300	16			110000	1.0
2230		16	330	120000	330	18			120000	1.0
2245	4.8	38	120	33000	1200	32	4.5		130000	0.3
2300			37	12000	1900	21			130000	0.1
2315		9.1	210	130000	210	9.4			140000	0.9
2330		8.9	200	120000	200	8.9			130000	0.9
2345		25	2200	14000	43				150000	0.1
2400			28	5700	5700	28			150000	0.04
2415			7.7	73	62000	1500	24	3.3	200000	0.3
2430				16	260	160000	260	12	160000	1.0
2445			9.6	120	120000	760	19		210000	0.6
0100				49	37000	49			37000	1.0
0115			5.6	2600	370	2.9			28000	0.1
0130				39	30000	39			30000	1.0
0145	5.9	1800	1800	5.9					47000	0.04

Figure 3.7


DOSE RATE AT MAXIMUM STATION
AND DIRECTLY UNDER THE PLUME
FOR THE PERIOD 2000 28 MARCH 1979
TO 0200 29 MARCH 1979
DOSE RATE (μR/hr)
10^5
10^4
10^3
DIRECTLY UNDER PLUME
MAXIMUM STATION
2000
2100
2200
2300
2400
0100
TIME

3.3 MONITORING SYSTEM RESPONSE TO HYPOTHETICAL ACCIDENT AT A BOILING WATER REACTOR

Calculations of the response of an environs monitoring system to a loss of coolant accident at a boiling water reactor were also made. The Oyster Creek site was selected for the calculations because of the availability of site meteorological data. The monitoring system was assumed to consist of 16 stations located at a distance of 1000 m from the reactor building. The average response of each detector was calculated during a 16-hour period beginning one hour after the presumed reactor scram.

3.3.1 Radionuclide Release Rates

The activity available for leakage from the drywell was taken to be the entire noble gas inventory one hour after the reactor scram. A noble gas activity leak rate of 0.1%/day direct to the environment was assumed (via the standby gas treatment system and the ~100-m chimney, without dilution in the reactor building). An additional 0.1%/day leak was assumed to be leaked into and mixed uniformly in the reactor building. The radiation field due to the airborne activity in the building was computed and added to that due to the postulated release from the chimney. The noble gas release was assumed to start at 0700 on 28 March 1979.

3.3.2 Meteorological Data

The actual 15-minute average meteorological data collected at the Oyster Creek site by Pickard, Lowe and Garrick were used to compute the dose from the noble gas plume. Figure 3.8 shows the average wind directions measured at the 116-m level during the 64 15-minute periods between 0700 and 2300 on 28 March 1979. A weather system was passing through the area during the period and a dramatic change in wind direction occurred. Wind speeds generally exceeded 4 m/s; hourly average values are shown in Figure 3.8. Atmosphere stability (based on the vertical temperature gradient) decreased from Class E to Class B and then returned to Class E. The stability classes for each hour are indicated by the letters on the right side of Figure 3.8.

3.3.3 Calculated Dose Rates

Figures 3.9 through 3.12 show the computed responses of the 16 detectors to the total radiation field from the plume and the reactor building. The plotted values include the natural background exposure rate of 7 μR/hr. The field from the reactor building (0-2 μR/hr) was the principal source of radiation at detector locations 2, 3 and 4 during the 16-hour period. The plume component of the field was dominant at the other stations when the wind carried the plume toward them. The highest dose rate calculated was about 2.4 mR/hr during the period of lower wind speeds. Predicted doses for later times were reduced by higher wind speeds, radioactive decay, and during some periods, better dispersion conditions.

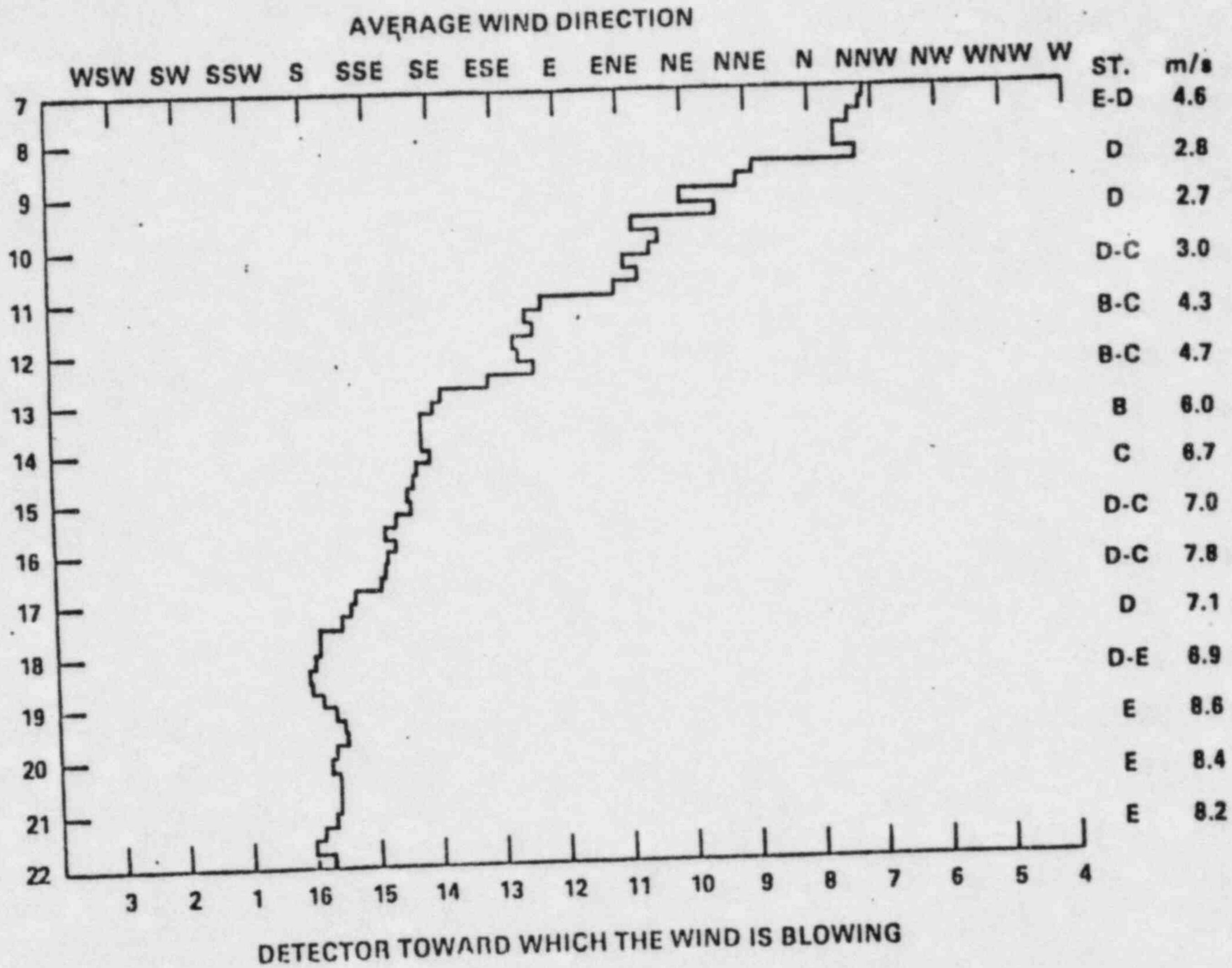

AVERAGE WIND DIRECTION
WSW SW SSW S SSE SE ESE E ENE NE NNE N NNW NW WNW W
ST. m/s
E-D 4.6
D 2.8
D 2.7
D-C 3.0
B-C 4.3
B-C 4.7
B 6.0
C 6.7
D-C 7.0
D-C 7.8
D 7.1
D-E 6.9
E 8.6
E 8.4
E 8.2
HOUR
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22
3 2 1 16 15 14 13 12 11 10 9 8 7 6 5 4
DETECTOR TOWARD WHICH THE WIND IS BLOWING

Figure 3.8

Figure 3.9

EXPOSURE RATE RESULTING FROM A HYPOTHETICAL ACCIDENT AT A BOILING WATER REACTOR

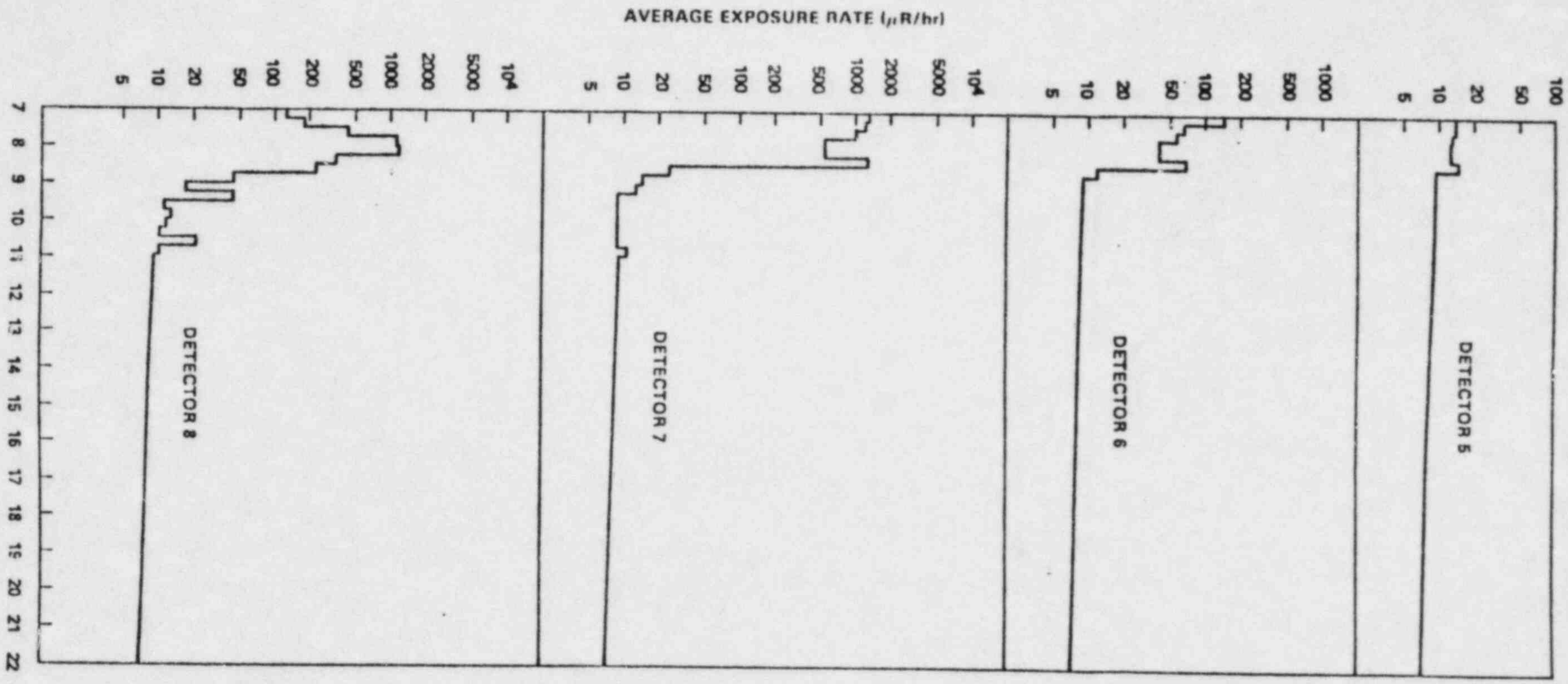


Figure 3.10

EXPOSURE RATE RESULTING FROM A HYPOTHETICAL ACCIDENT AT A BOILING WATER REACTOR

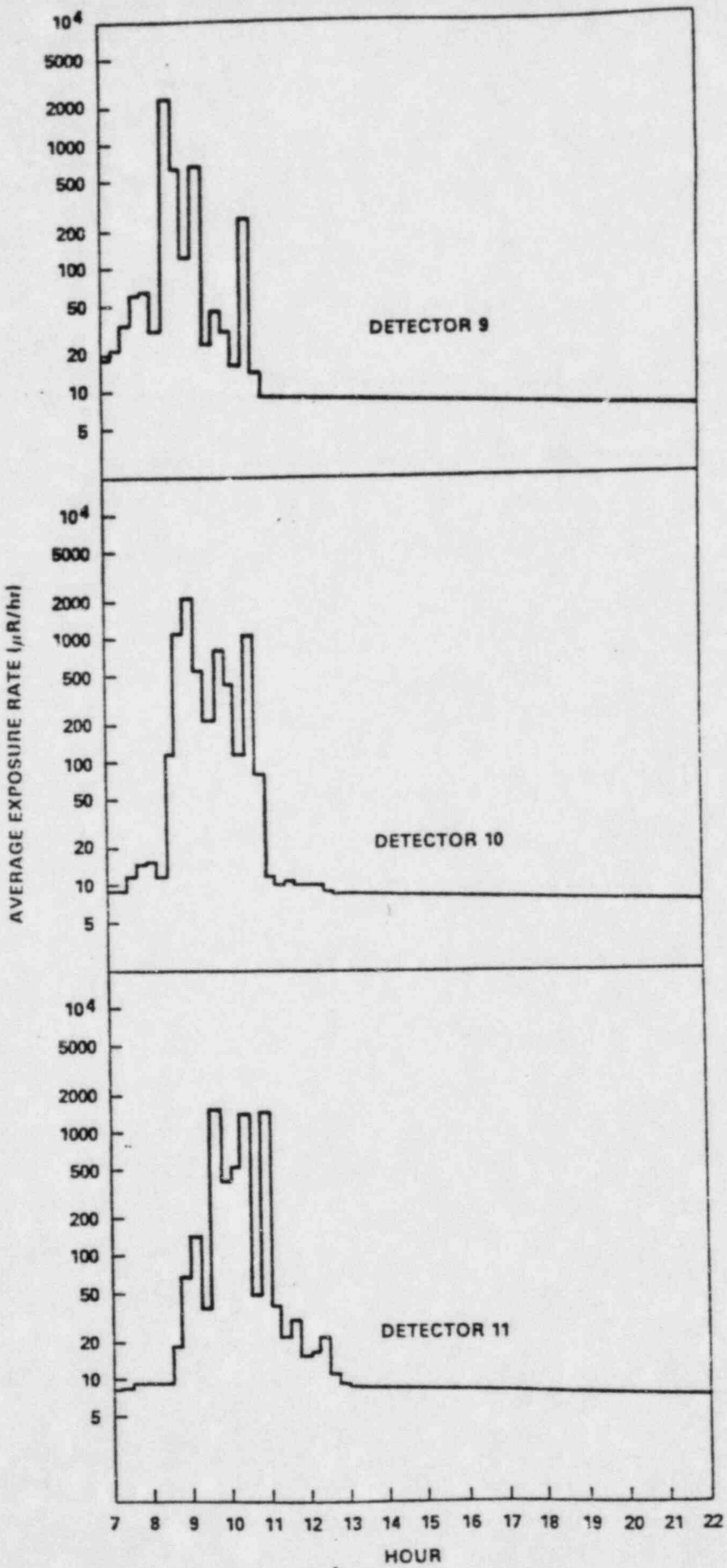
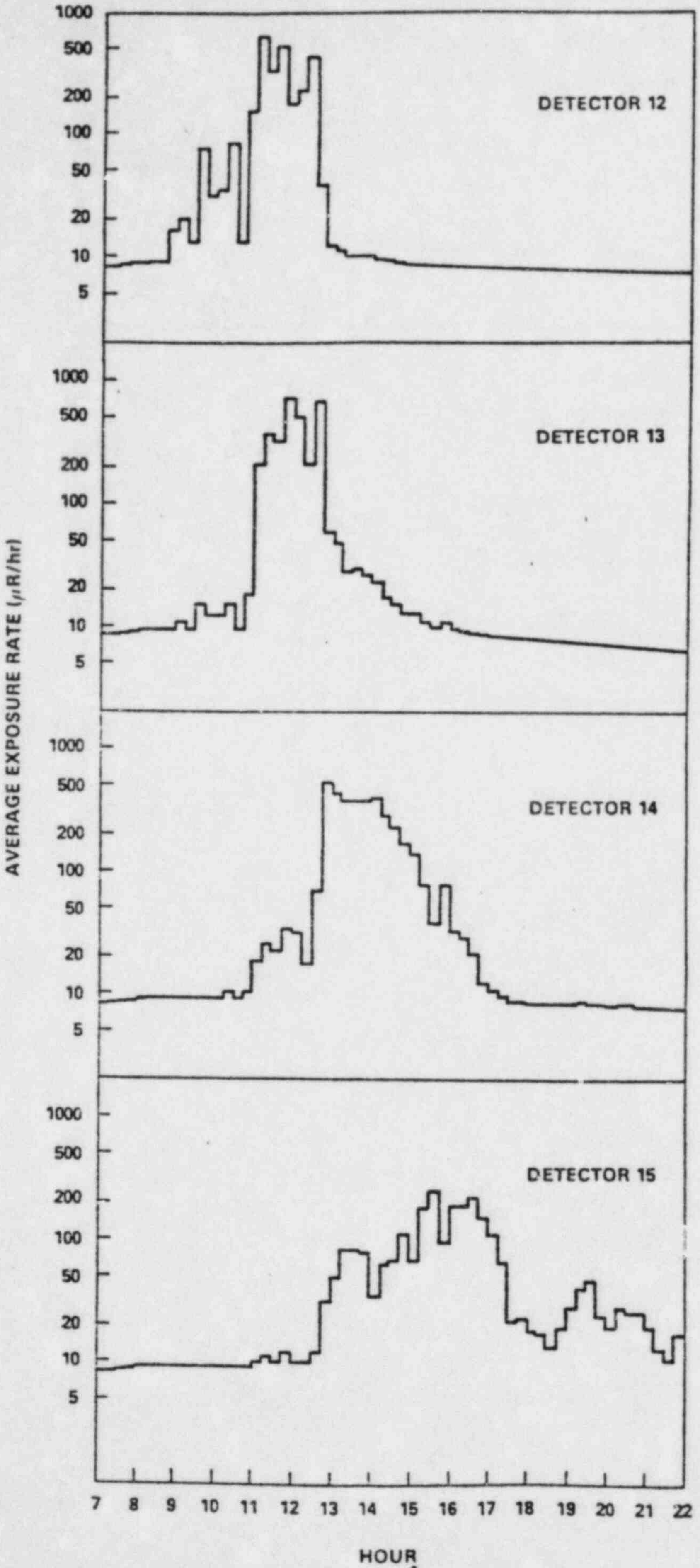


Figure 3.11

EXPOSURE RATE RESULTING FROM A HYPOTHETICAL ACCIDENT AT A BOILING WATER REACTOR



EXPOSURE RATE RESULTING FROM A HYPOTHETICAL ACCIDENT AT A BOILING WATER REACTOR

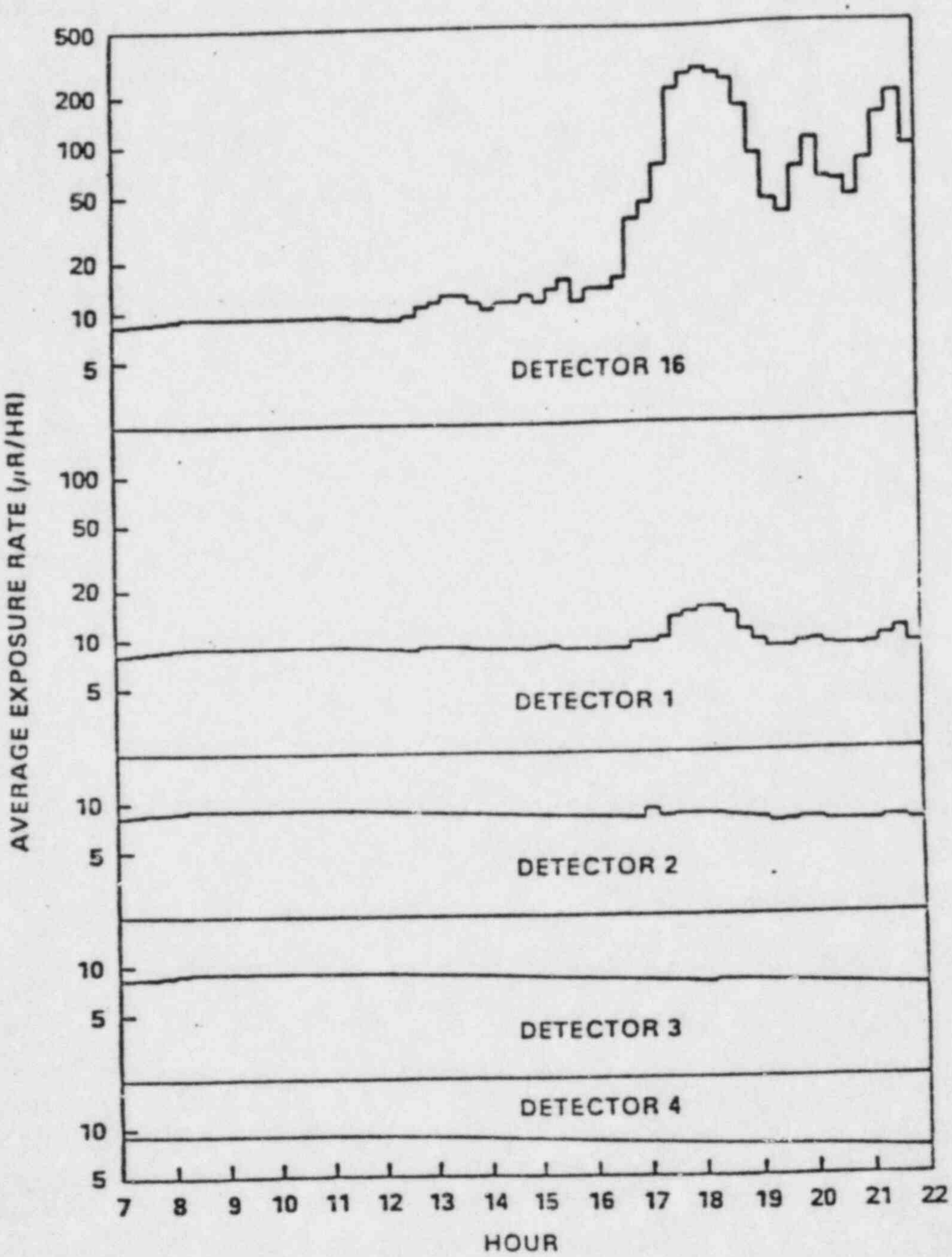


Figure 3.12

3.4 USE OF THE ENVIRONS MONITOR TO PROJECT DOSES FOR OTHER LOCATIONS

Current computational techniques use radiation release source terms and meteorological models to project dose rates. Derivation of the source term from environs monitoring data requires detailed knowledge or assumptions about the effective release height and energy spectrum of the source, and the meteorological conditions between the source and the monitors. Uncertainties in such a derivation could result in severe uncertainties in the estimated release rates. These would be compounded when combined with the uncertainties in the meteorological models used to compute dose rates at locations other than the monitor location.

The uncertainties in source term resulting from uncertainties in the release height or in the energy spectrum can be seen from the results in Section 2. Further, the vendors contacted did not have software that could estimate accurately the maximum dose along the plume centerline when the axis lies between two detectors. As can also be seen in the results of Section 2, this alone can severely affect the uncertainty in dose projection.

The uncertainties in dose rate estimates associated with meteorologic models will depend upon a number of factors. Principal among these are knowledge of the release location, the current meteorological conditions, and the diffusion climatology of the site. Even for relatively constant conditions, the response of a monitor in a fixed location will exhibit variability associated with minor changes in wind speed and direction that always occur. When meteorological conditions are changing, two types of uncertainty arise: (1) uncertainty in the location of the highest exposure rate at a particular distance due to changes in wind direction (both at the source and with distance from the source), and (2) uncertainties in the magnitude of that exposure rate due to changes in wind speed and stability. Stability changes can depend on season, time of day, and the existing regional weather pattern. Short term changes in wind speed and direction cannot be predicted reliably. Predictions of exposure rates at specific points are highly dependent on wind direction at the release point and the influences of terrain, buildings, wind shifts with distance and other factors. If either the site terrain or weather pattern is complex, then predictions of plume travel path will be highly uncertain and the dose rates predicted for specific points downwind may be grossly in error.

In summary, the accuracy that can be achieved when environs monitoring system data are used to predict dose rates at other locations depends upon the ability to calculate the source term and the accuracy of the meteorological models to project downwind doses. Considerable effort must be expended to achieve the first of these requirements and some of the computational algorithms were not available commercially at the time of our market survey.

SECTION 4

4.0 CRITERIA FOR INSTRUMENTATION AND ANALYSES

Instrumentation is required at both the remote stations and a central control location. Some data reduction capacity is needed at both locations. A functional block diagram of the instrumentation for a perimeter monitoring system is shown in Figure 4.1.

4.1 REMOTE STATIONS

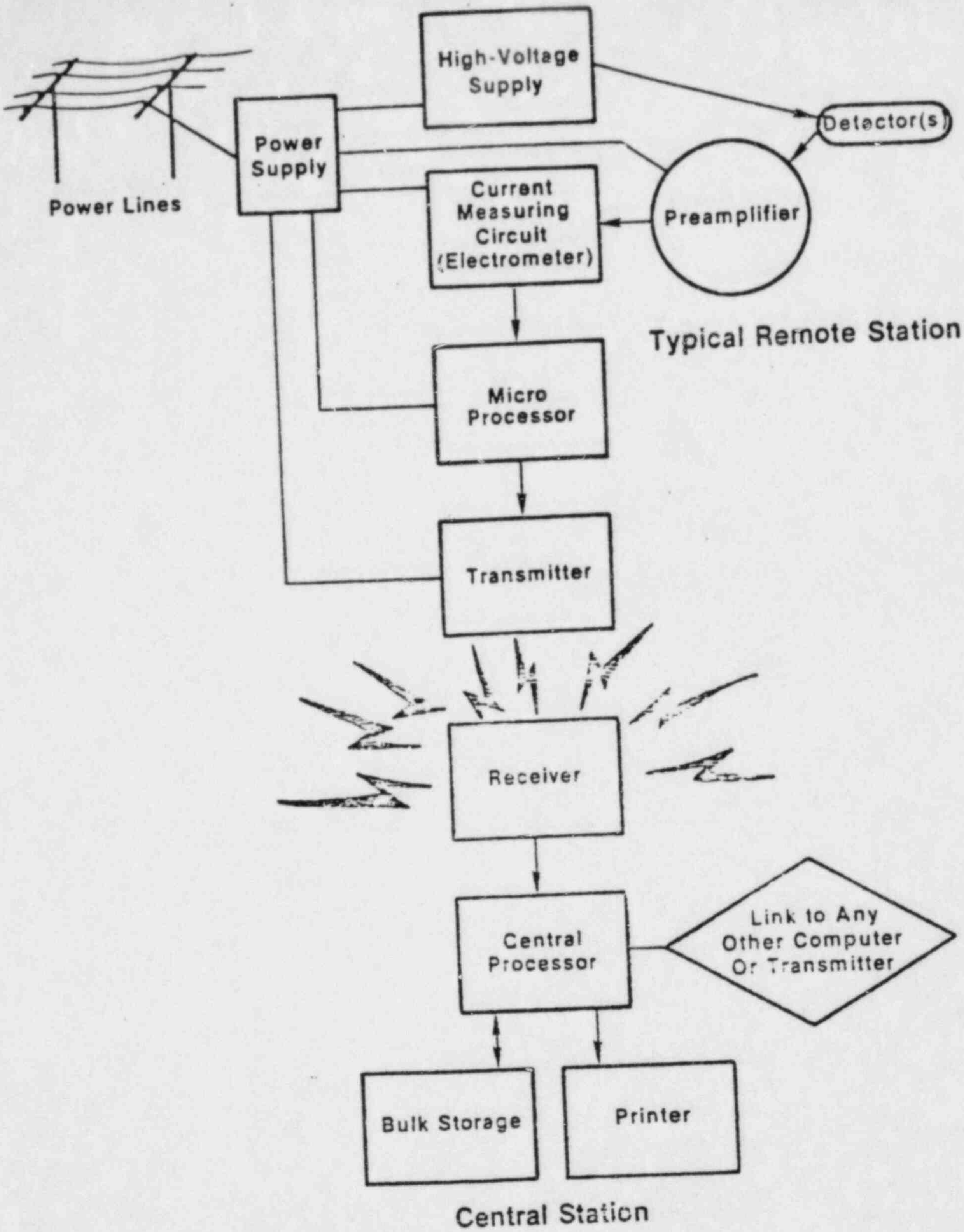
Each remote station will likely consist of a detector (or set of detectors), preamplifiers and current monitors (electrometers), a data storage and control microprocessor, and a data transmitter. Required ancillary equipment consists of power supplies, enclosures and environmental conditioners.

4.1.1 Detectors

The detectors will probably be ionization chambers or scintillation detectors. Both of these detector types can be used to measure dose rate.

4.1.1.1 Energy Response

Detectors used in the remote stations should be capable of measuring dose rate with reasonable accuracy (±10%) and are required (1) to respond to photons of energy 60 to 3000 keV. Releases of gaseous activity soon after an accident will contain a mixture of several noble gases that provides a complicated energy spectrum over the range 80-3000 keV. Because of this, it is highly desirable that the detector energy response be flat over the range from 60 to 3000 keV. Detector response should approximate that of an air ionization cavity as much as possible. This requires that the material of the detectors housing should be a low atomic number material so that the forward scattered Compton distribution from it is similar to that for air, and the scattered electronic equilibrium should also be maintained in the housing.



Block Diagram for Environs Exposure Rate Monitoring System

Figure 4.1

The required detector response at 60-keV demands relatively thin detector wall and environmental housing thicknesses. Another consideration that favors thin walls is that of dose build-up factors. The build-up results from Compton scattering of primary and secondary photons in the air surrounding the plume and the detector. The build-up factors are a function of both primary photon energy and distance. Spectra of scattered photons, also a function of primary energy, have been calculated (5,6).

Figure 4.2 shows probability distributions for the scattered photon energies as a function of incident photon energy. As can be seen from the data in the figure, most of the scattered gamma-rays have energies above 50 keV. For primary photons of 80 keV (^{133}Xe), 70% of the scattered radiation has an energy above 50 keV. Therefore, to accurately record dose from the scattered photons, a detector casing must be thin enough to pass 50-keV gamma-rays. A relative detector response of >70% at 50 keV is probably adequate.

4.1.1.2 Exposure Rate

The exposure rate range requested (1) for the perimeter monitors is from 1 μR/hr to 10^7 μR/hr. This range of seven decades is difficult to achieve with a single detector. If it cannot be done with a single unit, multiple detectors must be used. The use of multiple detectors complicates the system, however, because of duplication of components and logic elements at the remote stations. It is also difficult with multiple detectors to satisfy the desire of the NRC staff to have the detectors actively respond to ambient radiation levels at all times. This point is discussed further in Section 4.5.

4.1.1.3 Environmental Requirements

The remote stations will usually be located outside of any main buildings and either inside or outside the plant compound. Hence, the detectors will be subject to the weather conditions of the site, and they must be capable of operating in a temperature environment of -40 to +55 C$^{\circ}$ (-40 to +131 $^{\circ}$F) and in rain, snow and wind. To be environmentally qualified, the detectors must probably be placed inside small weatherproof enclosures that may contain considerable insulation to temper the rate of temperature changes. Heating of the enclosure in winter may also be required at the colder sites.

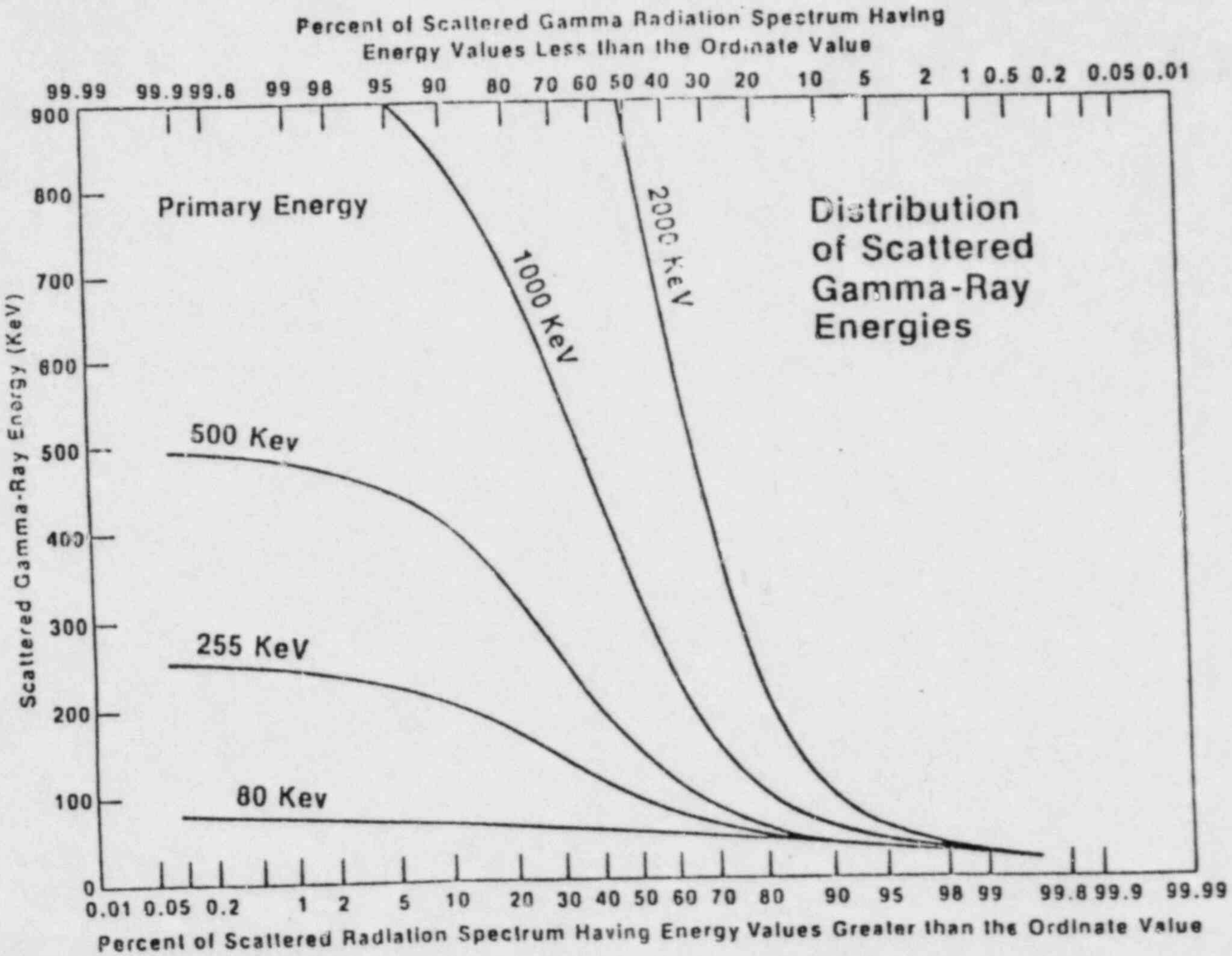

Percent of Scattered Gamma Radiation Spectrum Having
Energy Values Less than the Ordinate Value
99.99 99.9 99.8 99 98 95 90 80 70 60 50 40 30 20 10 5 2 1 0.5 0.2 0.05 0.01
900
800
700
600
500
400
300
200
100
0
Scattered Gamma-Ray Energy (KeV)
Primary Energy
1000 KeV
2000 KeV
500 Kev
255 KeV
80 Kev
Distribution
of Scattered
Gamma-Ray
Energies
0.01 0.05 0.2 1 2 5 10 20 30 40 50 60 70 80 90 95 98 99 99.8 99.9 99.99
Percent of Scattered Radiation Spectrum Having Energy Values Greater than the Ordinate Value

Figure 4.2

4.1.2 Electronics

The electronic instrumentation for the remote station typically consists of a detector high-voltage supply, preamplifier, current-to-voltage converter (electrometer), analog-to-digital converter (ADC) and a microprocessor.

4.1.2.1 Range, Accuracy and Computational Requirements

The range of the system as discussed above is from 1 μR/hr to 10 R/hr. If more than one detector is used to obtain this range, more than one set of electronics is probably required. Furthermore, a decade of operational range is necessary as an overlap between detectors to assure an adequate cross calibration. The microprocessor must either ascertain the proper detector data to transmit (and must transmit the data from both detectors during the overlap period) or must always transmit data from all detectors.

Minimum accuracy of data should be about 10% of the reading to achieve the desired (1) overall accuracy of ± half a decade. This degree of accuracy can be achieved with a low-resolution ADC (64-256 channel). The use of logarithmic current decoders is also desirable. Minimum requirements on the microprocessor are to (1) receive the data from the ADC(s), (2) periodically store these data (typically every 10 seconds), (3) calculate and store time averages (nominally 1-minute and 10-minute averages) and (4) on demand, transmit these data through the transmitter to the central controller. It is suggested that at least three hours of these averages be retained in the memory of the processor. A "push-down" stack memory is a possible technique.

4.1.2.2 Environmental Requirements

The electronic circuitry, as the detectors, must be able to withstand the extremes of the weather that include a temperature range of -40 to +55 C^{o} and heavy rains and winds. Unlike the detectors, the electronics may be placed in heavy duty enclosures either above or below the ground. Placement below the ground could offer additional advantages in physical security. Heating or cooling or both may be required to satisfy the temperature requirements.

4.1.3 Power Requirements

The power requirements (1) for the perimeter monitor are that it be "high reliability non-class 1E power, battery backed when momentary interruption is not tolerable". A battery backed system is usually more reliable because of the susceptibility of supply power lines to environmental damage. A battery operated system under "trickle charge" from the AC power is a very feasible method, but the capacity of a fully charged battery should be at least ten hours.

4.1.4 Transmitters

Three principal means exist to transmit data from the remote sites to the central station. These are:

1. direct wire connection,
2. dedicated telephone line, and
3. telemetry.

Direct connections often provide the most reliable method of data transmission. For many plants located on large rivers, this method may not be practical for stations across the river from the plant. Locations for running the cables via bridges, underwater, or overhead may not exist at the plant.

Practical telephone systems can be supplied by either AT&T or most independent telephone companies. An adequate telephone modem is produced by Western Electric Company. Data transmission can be over dedicated voice grade phone lines at up to 1600 baud rate. Half-duplex transmission (bidirectional, but one direction at a time) is adequate. The lines are usually dedicated and rented from a telephone company.

Several commercial vendors can supply telemetry systems. When the sender and receiver are on a line of sight and the distance between them is small (i.e., less than a mile or so), a low power frequency modulated (FM) system is adequate and does not require an FCC license. The central antenna for such a system can be elevated (on the meteorological tower, stack, etc.) to improve communication between the central and remote stations.

A typical system will be tailored to a specific plant site and may incorporate a combination of all of these means of data transmission. Data transmission

by direct wire and telephone is usually by digital pulses and that by telemetry is ordinarily by modulation of the FM carrier frequency. In all cases, the encoders and transmitters must be conditioned to withstand the extremes of the environment. They also will likely require an insulated weatherproof enclosure that may contain heating as well.

4.2 CENTRAL STATION

The central controlling station will be located within a plant building in an area such as the Technical Support Center or Control Center. It would consist typically of a data receiver and transmitter to communicate with the remote stations, a processor to analyze and store the data, a printer-keyboard and an interface to another device such as the plant computer or a data net. Communication will normally be through the keyboard.

4.2.1 Receiver and Transmitter

The receiver and transmitter unit must be capable of two-way communication with the satellite remote stations. The units are mates to the field units and the operating characteristics of the receiver and decoder must match. It is likely that the stations may be interrogated sequentially rather than simultaneously and that a "daisy chain" interrogation is acceptable.

4.2.2 Central Processor and Peripheral Hardware

The requirements of the controlling and data receiving processor are that it periodically (1) receive the sets of time averages (e.g., one-minute and ten-minute) from each remote station, (2) reduce further the data to obtain and store in permanent files time averages from each station, and (3) provide an interpretation of the data to give information on the magnitude of the activity in the plume and the direction in which it is traveling. Hardware requirements for this task are:

1. Automatically sequenced data receiver and decoder (or set of these devices),
2. Mini- or micro-processor with a probable minimum storage capacity of 4096 words,
3. Bulk data storage device such as magnetic tape, hard disk or floppy disk,
4. Printer and command entry keyboard, and

5. Associated interfaces including an interface (e.g., RS-232C) to another computer or phone link.

The processor should have automatic power-fail recovery so that data are not lost by short power interrupts such as might occur in a plant shutdown.

4.2.3 Data Analysis and Interpretation

In a typical application each station may transmit averages every five minutes. This results in 192 individual data points each hour for a typical system with sixteen remote stations. A simple listing of these data would not be particularly useful. There normally would be too much data to compile for an environmental or accident report. In an accident, the desired use of the system is to provide timely and as-accurate-as-possible data to aid in environmental assessment. Neither time nor personnel are generally available to perform lengthy analyses. Hence, the data analysis system should be capable of some minimum data interpretation as well as data reduction.

The data received by the central station must be identified by time and date and stored in a retrievable form in bulk storage. Additional desired data reduction would consist of calculating longer time averages (e.g., hourly and daily), storing these averages, writing reports and transmitting data to another system or to a data net either on demand or routinely. The system must also be able to write reports on demand. These requirements are not particularly demanding and require relatively simple programming. It is highly desirable that the programming be done using a universally understood source language such as FORTRAN IV or BASIC. The analysis program should provide analysis and reporting options so different analyses can be performed and reports printed as required.

The principal purpose for this system stated by the NRC in early drafts of Reference 1 was analysis of otherwise unmonitored releases from a plant. Ideal data interpretation from the Ring-Around-The-Station (RATS) would give the release rate (in Ci/s) from the unmonitored release. In practice this is nearly impossible. One must account for the contributions to the plumes from all of the monitored releases and one must know the size, location, altitude and gamma-ray energy spectrum of the plume activity to begin to calculate the unmonitored release rate. Most of these data are not well

known. In reality, the best practical analysis uses the data from the perimeter monitors to estimate the dose rate on the ground directly under the plume and verify the direction of transport of the plume.

Data interpretation at boiling water reactors (BWR) presents additional complications. An accident at a BWR can release a substantial fraction of the core inventory of fission gasses into the secondary containment of the reactor building. In such a case the direct radiation (shine) from the nearby unshielded reactor building can contribute a substantial dose rate to the perimeter stations (as much as or more than the plume itself). This contribution must be subtracted from the individual station readings before the dose from the plume can be computed. Some of the remote stations are partially shielded from the reactor building by various facilities, such as the turbine building. Hence, the response of each station to reactor building shine is both site and location dependent. It must be established at the time of system installation and included in the interpretative software.

Data interpretation for normal conditions at a plant will be dependent principally upon the desires of the customers. At a minimum they should consider radiation fields from radioactive waste handling and storage areas, liquid storage tanks, and the turbine building at a BWR. There may be other contributions to remote station readings that are site specific. If the detectors are to operate and the reporting is to be at environmental levels, the analyses might include the effects of rain-out of radon daughter activities, diurnal radon concentration variations and the effects of plumes from nearby industrial releases. Good environmental level analyses and presentation coupled with a good public relations program could be highly valuable to a utility. Graphics could be used advantageously.

4.3 ENVIRONMENTAL QUALIFICATIONS

The NRC has not required that the perimeter monitor including the installation be seismically qualified; but it should conform to the requirements of NUREG-0588. This has been further interpreted to state (1), "Instrumentation components should be installed consistent with the criteria of the Uniform Building Code applicable to the building or structure in which the instrumentation components are mounted or housed", and "Assurance must be obtained that equipment has been designed and qualified to meet its performance and service requirements". Our interpretation is that it must be demonstrated by design and construction review that system will operate under the normal and accident conditions to which it will be subjected.

4.4 QUALITY ASSURANCE LEVELS

Requirements for a vendor's quality assurance program are highly subjective. In most cases they will be established by the purchaser rather than by the NRC. At a minimum the vendor must have a quality assurance and quality control program and must provide complete engineering drawings, manuals and documentation of calibrations. The calibrations must be traceable to the National Bureau of Standards (NBS).

4.5 SYSTEM CALIBRATION

The detectors and electronics for each remote station must be calibrated to give the conversion factors relating detector current output to dose rate (R/hr). This in turn must be related to give the signal at the output of the decoder at the central station in terms of dose rate at each detector. This must be done as a function of gamma-ray energy over the range from 60 to 3000 keV. It is probably sufficient to do this at only a few energies (e.g., 60, 355, 663 and 1275 keV). Because of the nature of the detectors that will probably be used, only periodic verification calibrations need be performed after the initial extensive calibration is completed.

Members of the NRC staff have expressed a desire that all detectors in a system be actively reading at all times. This would include all detectors used to achieve the seven-decade range requested (1). It is possible to achieve this

feature in the higher-range detectors by depositing a beta emitting source on the inside of the detector chamber. Such a source could also serve as a continuous calibration verification for these detectors. At the sacrifice of very low-level environmental monitoring, such a source could also be included with the low-level sensor. Alternatively, the time variations in the background exposure rate could be used.

4.5.1 Primary Calibration

The system vendor will likely do the initial or primary detector calibration. Sources, denoted here as primary sources, should be used. The primary sources are calibrated with an air cavity ionization chamber. This calibration should either be done at the NBS or with a chamber calibrated by the NBS. There should be a collection of these sources that covers the energy range 60 to 3000 keV. Typical sources could be ^{241}Am, ^{133}Ba, ^{137}Cs and ^{60}Co. System calibrations should yield the conversion constant for the output of the decoder at the central station. This should be determined for each energy over the range of the entire detector system (1 μR/hr to 10 R/hr) with measurements at values such as 10 μR/hr, 100 μR/hr and 1 mR/hr, 100 mR/hr and 1 R/hr. Documentation of these measurements must be supplied to the purchaser.

Calibrations must effectively treat the effect of dose buildup from scattered radiation. The normal and acceptable technique is to use a shadow shield between the source and detector to measure the buildup dose. Subtraction of this reading from the dose measured with no shield yields the dose from the unscattered radiation. The primary sources must have been calibrated in the same manner.

4.5.2 Field Calibrations

Periodic field calibration verifications are necessary. These can likely be done at only a few energies such as 60 and 663 keV and at only one or two dose rates in each detector range. The detectors may be supplied with the beta source on the inner surface of the chamber so as to have each detector be actively reading at all times. If this were done, some calibration verification is done continuously and additional calibration requirements can be less extensive. Field calibration verifications should be done at least every six months.

If the verification measurements show that a detector has changed its efficiency by more than an established amount (e.g., 25%), it should be replaced. The replacement detector should receive a primary calibration to relate output current to dose rate and the output current must be related to the output of the central station decoder.

Section 5

5.0 COSTS

In determining the initial cost for a perimeter monitoring system the following items must be considered:

1. Detectors and associated electronics at the remote stations.
2. Data transmission from the remote station.
3. Central receiving and processing system.
4. Installation.

The cost estimates for detectors, data transmission and the central system were obtained from vendors of such equipment while the costs associated with installation of the equipment were supplied by various utilities.

5.1 DETECTORS AND ELECTRONICS AT THE REMOTE STATIONS

Each remote station will include a detector with its associated electronics, including a microprocessor data handling device. This equipment is estimated to cost $10,000 to $15,000 for each remote station.

5.2 DATA TRANSMISSION FROM THE REMOTE STATION

Three methods of data transmission were considered: telephone, telemetry via FM signal and a hard-wired cable transmission. A signal processor for telephone transmission will cost $1,000 to $1,500 for each station. Telemetry via FM transmission would cost about $4,000 per station. The costs for a hard-wire system are included in the installation costs given below.

5.3 CENTRAL RECEIVING AND PROCESSING SYSTEM

The central data receiving and processing system will include a data receiver and transmitter, a central processing unit and a printer/keyboard I/O device. The cost for this is estimated to be $50,000 to $60,000.

5.4 INSTALLATION

For a telephone communication or a telemetry system about $500 per station should be sufficient for the actual installation. In addition about $2,000 to $3,000 per station would be required for design, engineering and fabrication. The costs for installation of each station could be increased another $1,000 if it is necessary to include enclosures and temperature control devices to heat and/or cool the electronics.

Installation costs for a hard-wired system could be quite large. One utility that has installed a hard-wired system of six stations estimates the present cost of installation would be about $67,000 per station. Another utility has made a recent cost estimate for a 16-station hard-wired system to be located 500 m from the center of the Auxiliary Building of a 2-unit nuclear generating station. Seven of the locations would be in the cooling pond at that distance, a factor that has a significant bearing on the costs. The total costs for four alternatives vary from $1.1-1.2 million to $1.9-2.0 million. The lower range applies to options that sacrifice uniformity of radial distance to obtain sites on solid ground. That is, the cost of installing 7 systems in a cooling pond is ~$0.8 million more than installing them on dry land. The variance within the two ranges given is $60-70 thousand which represents the cost differential between providing an uninterrupted power supply (UPS) from the Auxiliary Building and providing power from the nearest available sources.

5.5 ESTIMATED COSTS FOR A 16 STATION RING

Based on the information above the range of cost for a 16 station environs monitoring system would be:

Detectors and Associated Electronics	$160,000	to	$240,000
Data Transmission	16,000		64,000
Central Processor	50,000		60,000
Installation	40,000		2,000,000
Total System Cost	$266,000		$2,364,000

5.6 ESTIMATED COSTS FOR GREATER THAN 16 STATIONS

The recent cost data employed in making the estimates given above can be used to evaluate the costs of larger hard-wired systems at the same site.

Doubling the number of stations to 32, all on or near the 500 m arc, would approximately double the cost estimates given above for the various options considered. Thus a totally land based system containing 32 stations at ~500 m would be expected to cost $2.2-2.4 million. The cost of a double ring of stations can also be estimated. For 16 stations on both the 500 m and 1000 m arcs, the total costs estimated on the same basis would be $3.4-3.6 million.

REFERENCES

1. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.97 Revision 2, "Instrumentation for Light Water Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident" (December 1980).

   The present study was begun shortly after issuance of Draft 2 of Proposed Revision 2 of Regulatory Guide 1.97 (June 4, 1980). This study addresses criteria in that draft. These included the following:

   Purpose

   > "For estimating release rates of radioactive materials released during an accident from unidentified release paths (not covered by effluent monitors) - continuous readout capability. (Approximately 16 to 20 locations - site dependent)."

   Requirements

   1. The ability to measure dose rates in the range 10^{-6} R/hr to 10 R/hr.
   2. Environmental Qualification per Regulatory Guide 1.89 (NUREG-0588).
   3. A high reliability power source, non-Class 1-E, battery backed when momentary interruption is not tolerable.
   4. Periodic testing per Regulatory Guide 1.118.
   5. Detectors should respond to gamma radiation photons within any energy range from 60 keV to 3 MeV with an accuracy of ± 20% at any specific photon energy from 0.1 MeV to 3 MeV. Overall system accuracy should be within ± 1/2 decade over the entire range.

2. D. H. Slade (Ed.), Meteorology and Atomic Energy, USAEC Division of Technical Information, TID-24190 (1961).

3. R. G. Canada, NSAC EPRI ORIGEN CODE Calculation of the TMI-2 Fission Product Inventory, Technology for Energy Corporation Report R-80-012 (May 1980).

4. Assessment of Offsite Doses From the Three Mile Island Unit 2 Accident, TDR-TMI-116.

5. H. Goldstein and J. E. Wilkins, Jr., Calculations of the Penetration of Gamma Rays, NYC-3075 (June 1954).

6. L. D. Gates, Jr. and C. Eisenhauer, Technical Analysis Report, AFSWP 502A (January 1954).

APPENDIX A

Questionnaire

Vendors Contacted By Mail

Vendors Contacted By Telephone

QUESTIONNAIRE

INSTRUMENTATION AVAILABLE FOR APPLICATION
TO A REMOTE MONITORING STATION SYSTEM

1. Do you manufacture an instrument with a single detector capable of measuring the range from 10^{-6} R/hr to 10 R/hr? ___ Yes ___ No

2. If the answer to question 1 is "No": Do you provide a system using multiple detectors capable of measuring the range from 10^{-6} R/hr to 10 R/hr? ___ Yes ___ No

3. If the answer to question 1 is "No": Do you manufacture an instrument containing a single detector capable of measuring an upper limit of 10 R/hr? ___ Yes ___ No

   What is the lower sensitivity of this device? ________

4. Is this instrument presently commercially available? ___ Yes ___ No

5. Can this instrument be environmentally qualified (i.e., non-seismic, IEEE 323, 1974)? ___ Yes ___ No

VENDORS CONTACTED BY MAIL

1.	Applied Physical Technology, Inc.	D. M. Walker
2.	Atomic Products Corporation	James Reiss
3.	Canberra Industries, Inc.	G. Leskowski
4.	Catalytic Products International, Inc.	E. Betz
5.	Digital Data Dosimetry Inc.	L. Lay
6.	Dosimeter Corporation of America	M. Srybnik
7.	Eberline Instrument Corporation	Eric L. Geiger
8.	EG&G Ortec Inc.	John Haynes
9.	Electrometer Corporation	Al Zirkes
10.	Fluid Components, Inc.	M. M. McQueen
11.	Foxboro Analytical	Carol Tunick
12.	General Atomic Co.	R. J. Robby
13.	The Harshaw Chemical Company	Harry Cobble
14.	Health Physics Instruments, Inc.	J. Handloser
15.	High Voltage Engineering Corp.	R. L. Malnati
16.	Johnston Laboratories, Inc.	L. Gevins
17.	Kaman Sciences Corporation	Jim Lee
18.	Kimmel, Inc.	William L. Weiss
19.	Kurz Instruments, Inc.	Bob Steinberg
20.	Leeds and Northurp	H. A. Selko
21.	Meteorology Research, Inc.	A. L. Severson
22.	Murray and Trettel, Inc.	Jack Coblenz
23.	National Nuclear Corporation	H. Miller
24.	Nuclear Equipment Chemical Corporation	B. Backstrom
25.	Nuclear Instrument Company	K. Gerrish
26.	Nuclear Measurements Corporation	Mr. Hildenbrand
27.	Nuclear Power Outfitters	Earl E. Jacobson
28.	NUS Corporation	L. R. Love
29.	Nuclear Research Corporation	D. T. McIntyre
30.	Par Systems	Mike Ryder
31.	Princeton Gamma-Tech, Inc.	R. J. Williams
32.	Radiation Management Corporation	Thomas O'Malley
33.	Radiation Monitoring Devices, Inc.	Elisa Redler
34.	Reuter-Stokes, Inc.	Annette Eeckhout
35.	SAI Technology	Francis Smith
36.	Schmidt Instrument Company	A. C. Schmidt
37.	Sierra/Misco, Inc.	J. R. Andre
38.	Technical Associates	J. R. Starr
39.	Technology For Energy Corporation	Bill Hartman
40.	Air Monitor Corporation	Ted Andrews
41.	Teledyne Analytical Instruments	Victor Black
42.	TERA Corporation	Robert W. Felton
43.	Terradex Corporation	J. Gingrich
44.	Texas Instruments, Inc.	J. T. Major
45.	Victoreen Instrument, Inc.	Jeanee C. Moriarty
46.	Westinghouse Instrument Division	R. Higgenbotham
47.	Weston Components and Controls Division	J. L. Walsh
48.	Xetex, Inc.	K. F. Sinclair
49.	General Electric	

VENDORS CONTACTED BY TELEPHONE

1.	Applied Physical Technology, Inc.	D. M. Walker
2.	Eberline Instrument Corporation	Eric L. Geiger
3.	EG&G Ortec Inc.	John Haynes
4.	General Atomic Company	R. J. Robby
5.	The Harshaw Chemical Company	Harry Koppel
6.	Kaman Sciences Corporation	Jim Lee
7.	Kimmel, Inc.	William L. Weiss
8.	Nuclear Measurements Corporation	Mr. Hildenbrand
9.	Par Systems	Mike Ryder
10.	Radiation Management Corporation	Thomas O'Malley
11.	Reuter-Stokes, Inc.	Annette Eeckhout
12.	Technology For Energy Corporation	Bill Hartman
13.	Westinghouse Instrument Division	R. Higgenbotham

APPENDIX B

Results From Parametric Study

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 250.00 METERS
HEIGHT OF RELEASE POINT = 0.000 METERS
STABILITY CLASS = 1

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	4.35309E-03	9.71266E-03	4.70568E-02
2	0.196	3.35981E-03	7.41185E-03	3.55910E-02
3	0.393	1.88228E-03	4.26977E-03	2.02965E-02
4	0.785	3.65454E-04	1.07109E-03	5.42973E-03
5	1.571	4.40382E-05	2.23126E-04	1.48027E-03

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 250.00 METERS
HEIGHT OF RELEASE POINT = 0.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	2.28344E-02	5.92463E-02	2.99731E-01
2	0.196	3.89500E-03	8.15364E-03	3.86941E-02
3	0.393	1.41504E-03	3.23596E-03	1.51406E-02
4	0.785	2.97290E-04	9.70643E-04	5.07330E-03
5	1.571	3.63468E-05	1.98433E-04	1.39591E-03

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 250.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 1

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

B-4

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.29465E-03	3.00228E-03	1.40792E-02
2	0.196	1.11839E-03	2.64162E-03	1.25249E-02
3	0.393	7.25131E-04	1.84929E-03	8.99026E-03
4	0.785	2.18404E-04	7.44111E-04	4.02144E-03
5	1.571	3.13244E-05	1.78024E-04	1.27611E-03

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 250.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.27822E-03	2.99388E-03	1.40672E-02
2	0.196	1.03625E-03	2.53045E-03	1.19875E-02
3	0.393	6.25982E-04	1.71429E-03	8.38194E-03
4	0.785	1.82363E-04	6.80479E-04	3.84594E-03
5	1.571	2.60185E-05	1.59187E-04	1.19984E+03

S U M M A R Y   O F   D E T E C T O R   R E S P O N S E   T O   P L U M E

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT OF RELEASE POINT = 0.000 METERS
STABILITY CLASS = 1

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.34421E-03	3.13643E-03	1.52489E-02
2	0.196	1.01281E-03	2.42808E-03	1.19315E-02
3	0.393	4.32916E-04	1.17730E-03	6.16961E-03
4	0.785	2.78573E-05	1.64765E-04	1.32364E-03
5	1.571	5.15090E-07	1.20244E-05	2.30553E-04

S U M M A R Y O F D E T E C T O R R E S P O N S E T O P L U M E

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT-OF-RELEASE-POINT = 0.000 METERS
STABILITY CLASS = 3

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	4.39269E-03	9.77410E-03	4.75159E-02
2	0.196	1.96168E-03	4.50810E-03	2.17388E-02
3	0.393	3.53874E-04	1.09630E-03	5.86396E-03
4	0.785	1.66166E-05	1.36671E-04	1.23033E-03
5	1.571	4.30277E-07	1.06625E-05	2.11273E-04

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT OF RELEASE POINT = 0.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.23599E-02	2.95071E-02	1.48143E-01
2	0.196	1.42557E-03	3.32462E-03	1.59056E-02
3	0.393	2.51164E-04	9.22009E-04	5.19990E-03
4	0.785	1.31731E-05	1.26878E-04	1.24685E-03
5	1.571	4.06096E 07	1.06560E-05	2.26790E-04

S U M M A R Y O F D E T E C T O R R E S P O N S E T O P L U M E

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT-OF-RELEASE-POINT = 50.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	3.42262E-03	7.23196E-03	3.44413E-02
2	0.196	1.10794E-03	2.71611E-03	1.31309E-02
3	0.393	2.22944E-04	8.49738E-04	4.87803E-03
4	0.785	1.23470E-05	1.21591E-04	1.21287E-03
5	1.571	3.88599E-07	1.03438E-05	2.22917E-04

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 1

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.07062E-03	2.55276E-03	1.25629E-02
2	0.196	7.92470E-04	1.95206E-03	9.75494E-03
3	0.393	3.41193E-04	9.69054E-04	5.21045E-03
4	0.785	2.23204E-05	1.42512E-04	1.21241E-03
5	1.571	4.32003E-07	1.08179E-05	2.20679E-04

S U M M A R Y O F D E T E C T O R R E S P O N S E T O P L U M E

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 3

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.24207E-03	2.96750E-03	1.43875E-02
2	0.196	7.22146E-04	1.90323E-03	9.52417E-03
3	0.393	2.07863E-04	7.57475E-04	4.34105E-03
4	0.785	1.26918E-05	1.14[illegible]E-04	1.09491E-03
5	1.571	3.57291E-07	9.44095E-05	1.96943E-04

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 500.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.24660E-03	2.98602E-03	1.43237E-02
2	0.196	6.20967E-04	1.75641E-03	8.87775E-03
3	0.393	1.59643E-04	6.77325E-04	4.09982E-03
4	0.785	1.02058E-05	1.07303E-04	1.11901E-03
5	1.571	3.39346E-07	9.47613E-06	2.12014E-04

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 1000.00 METERS
HEIGHT OF RELEASE POINT = 0.000 METERS
STABILITY CLASS = 1

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	350	1500
1	0.000	2.03349E-04	5.62064E-04	3.16046E-03
2	0.196	1.42139E-04	4.08724E-04	2.40460E-03
3	0.393	4.51378E-05	1.54335E-04	1.09716E-03
4	0.785	3.58432E-07	5.24940E-06	1.30730E-04
5	1.571	5.66095E-11	3.15005E-08	9.16617E-06

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 1000.00 METERS
HEIGHT OF RELEASE POINT = 0.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	7.85988E-03	1.80974E-02	8.96188E-02
2	0.196	2.70508E-04	9.44299E-04	5.37249E-03
3	0.393	9.00663E-06	9.85388E-05	1.13666E-03
4	0.785	2.15696E-08	2.01104E-06	1.21242E-04
5	1.571	3.74039E-11	2.61079E-08	9.26737E-06

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 1000.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 1

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	2.11186E-04	5.79023E-04	3.23787E-03
2	0.196	1.39531E-04	4.05018E-04	2.38411E-03
3	0.393	3.95018E-05	1.43460E-04	1.04313E-03
4	0.785	3.39562E-07	5.09029E-06	1.30717E-04
5	1.571	5.29477E-11	3.05939E-08	9.28422E-06

SUMMARY OF DETECTOR RESPONSE TO PLUME

RADIUS OF DETECTOR CIRCLE = 1000.00 METERS
HEIGHT OF RELEASE POINT = 100.000 METERS
STABILITY CLASS = 6

DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)

DETECTOR	ANGLE (RADIANS)	ENERGY (KEV) 80	250	1500
1	0.000	1.16705E-03	2.82802E-03	1.37144E-02
2	0.196	1.65744E-04	6.79945E-04	4.18188E-03
3	0.393	7.04282E-06	8.41898E-05	1.03239E-03
4	0.785	1.88791E-08	1.84568E-06	1.15760E-04
5	1.571	3.40361E-11	2.45550E-08	8.98220E-06

APPENDIX C

LISTING OF PROGRAM PLUME

A routine to calculate the response of detectors to the activity in a plume released during an accident.

```
      C       PROGRAM PLUME
      C
      C       ROUTINE TO CALCULATE THE RESPONSE OF DETECTORS PLACED IN A
      C       RING ABOUT A NUCLEAR POWER PLANT TO THE ACTIVITY IN A PLUME
      C       RELEASED DURING AN ACCIDENT.
      C
      C       THE CALCULATION MODEL ASSUMES THAT N DETECTORS ARE PLACED
      C       AROUND THE PLANT ON A CIRCLE OF RADIUS, RAD, METERS. THE
      C       RELEASE POINT IS AT THE CENTER OF THE CIRCLE AT A HEIGHT,
      C       H, METERS.
      C
      C       THE PLUME MOVES ALONG THE X AXIS OF THE COORDINATE SYSTEM
      C       AWAY FROM THE PLANT. THIS AXIS IS AT AN ANGLE, PHI, TO
      C       ANY DETECTOR. THE PLUME DIVERGES ACCORDING TO THE STABILITY
      C       CLASS (NCLASS = A TO G)
      C       THE CALCULATIONS ASSUME THAT THE WIND SPEED AND THE RELEASE
      C       RATE ARE 1 UCI PER SECOND AND 1 METER PER SECOND,RESPECTIVELY.
      C
      C       THE CONCENTRATION AT ANY POINT WITHIN THE PLUME IS COMPUTED
      C       THROUGH AN ALGORITHM GIVEN BY J.N.HAMAWI, OCTOBER 1971,
      C       ..PLUMDOS.. YANKEE ATOMIC ELECTRIC CO.
      C
      C       GAMMA-RAY ATTENUATION COEFFICIENTS HAVE BEEN FIT TO A QUADRATIC
      C       IN THE LOG OF THE ENERGY AS:
      C       ......MU=EXP(-3.1577-0.0265 LN(E) -0.03352 (LN(E))**2)...TOTAL
      C       ..................AND.........................................
      C       .....XMU=EXP(-1.8770-1.6300 LN(E) +0.16800 (LN(E))**2)  <400 KEV
      C       ........=EXP(-9.0220+1.1146 LN(E) -0.09175 (LN(E))**2)  >400 KEV
      C       ..................ABSORPTION COEFFICIENT......................
      C
      C       BUILD-UP FACTORS HAVE BEEN TAKEN FROM:
      C           NUCLEAR SCIENCE AND ENGINEERING   V.73 1980  97-107
      C           CHILDEN,EISENHAUER, & SIMMONS
      C       THEY HAVE BEEN FIT TO THE EQUATION
      C            BUF=1+EXP(A1+A2 LN(MFP) +A3 (LN(MFP))**2)
      C         WHERE     A1=3.16911-0.29236 LN(E) -0.02765 (LN(E))**2  <200 KEV
      C            =4.2723 -0.80324 LN(E) +0.020071(LN(E))**2  >200 KEV
      C          A2=-2.47496+1.61249 LN(E) -0.16468 (LN(E))**2 <200 KEV
      C            = 0.99512+0.23052 LN(E) -0.027981(LN(E))**2 >200 KEV
      C          A3=-3.35150+1.45130 LN(E) -0.14678 (LN(E))**2 <200 KEV
      C            = 0.93913-0.46538 LN(E) +0.02786 (LN(E))**2 >200 KEV
      C
      C       INTEGRATION IS OVER X,Z,Y, RESPECTIVELY, WITH TERMINATION
      C       WHENEVER A PARTICULAR VALUE IS LESS THAN MAX/2000.
      C       THE BIN SIZES FOR THE NUMERICAL INTEGRATION IN Y AND Z COORD
      C       ARE SET EQUAL TO SIGMA Y /5  AND SIGMA Z /5,RESPECTIVELY.
      C       THAT FOR X IS AN INPUT PARAMETER.
      C
0001          DIMENSION PYK(4,7),PZK(4,7),E(3),A11(6),A22(6),A33(6),U(3)
             1,RES(30,4),UA(6),PHI(9),CUE(20,2),ICUE(20,2)
      C       COEFFICIENTS FOR PLUME DIFFUSION
0002          DATA X1,X2,X3/4.6052,6.9078,9.2103/
      C       Y DIFFUSION COEFFICIENTS.
0003          DATA PYK/5.135,0.9439,-0.01012,-0.001682,2.777,0.9729,-0.01535
```

```
              1,-0.000177,2.518,0.9402,-0.007994,-0.0004241,2.104,0.9334
              2,-0.006178,-0.001078,1.808,0.9367,-0.00751,-0.000731,1.386
              3,0.9629,-0.01615,0.001037,0.9933,0.9306,-0.003981,-0.001395/
        C      Z DIFFUSION COEFFICIENTS.
               DATA PZK/2.741,1.53,0.2009,-0.037,2.416,1.081,0.1612,-0.00[illegible]59
              1,2.016,0.9428,-0.02774,-0.0002219,1.571,0.8259,-0.04077,0.00116
              2,1.261,0.8142,-0.05579,0.0003467,0.8502,0.7709,-0.05184,0.00035
              3 33,0.4383,0.7543,-0.0581,0.0006759/
        C      GAMMA-RAY ENERGIES.
0005           DATA E/80.,250.,1500./
        C      BUILD-UP FACTOR COEFFICIENTS.
0006           DATA A11/3.16911,-0.29236,-0.02765,4.2723,-0.80324,0.028071/
0007           DATA A22/-2.47496,1.61249,-0.16469,0.99512,0.23052,-0.027981/
0008           DATA A33/-3.3515,1.4513,-0.14678,1.93913,-0.46538,0.02786/
        C      GAMMA-RAY ATTENUATION COEFFICIENTS.
0009           DATA U/-3.1577,-0.0265,-0.03352/
        C      GAMMA-RAY ABSORPTION COEFFICIENTS.
0010           DATA UA/-1.877,-1.63,0.168,-9.022,1.1146,-0.091753/
        C      ANGLES TO BE CALCULATED.
0011           DATA PHI/0.,0.0491,0.0982,0.1963,0.3927,0.7854,1.5708,2.3562,3.1416/
        C
        C      ..............INPUT DATA.........................
0012           TYPE 2
0013           ACCEPT 20,INC
0014              DO 500 IC=1,INC
0015              TYPE 5                          !RADIUS OF DETECTOR CIRCLE?
0016              ACCEPT 10,CUE(IC,1)
00                TYPE 30                         !STACK HEIGHT?
0(                ACCEPT 10,CUE(IC,2)
                  TYPE 35                         !STABILITY CLASS?
0020              ACCEPT 15,ACLASS
0021              IF(ACLASS.EQ.'A')ICUE(IC,1)=1
0023              IF(ACLASS.EQ.'B')ICUE(IC,1)=2
0025              IF(ACLASS.EQ.'C')ICUE(IC,1)=3
0027              IF(ACLASS.EQ.'D')ICUE(IC,1)=4
0029              IF(ACLASS.EQ.'E')ICUE(IC,1)=5
0031              IF(ACLASS.EQ.'F')ICUE(IC,1)=6
0033              IF(ACLASS.EQ.'G')ICUE(IC,1)=7
0035              TYPE 40                 ! XBIN LENGTH
0036              ACCEPT 20,ICUE(IC,2)
0037     500   CONTINUE
        C
0038           CALL ASSIGN(6,'LP:')
        C
        C      CALCULATION LOOP
0039           DO 3000 IC=1,INC
0040           RAD=CUE(IC,1)
0041           HA=CUE(IC,2)
0042           NCLASS=ICUE(IC,1)
0043           NXBIN=ICUE(IC,2)
        C      .............RELEASE HEIGHT LOOP.....  ...............
0044           IF(ICUE(IC,1).EQ.1)ACLASS='A'
0              IF(ICUE(IC,1).EQ.2)ACLASS='B'
0              IF(ICUE(IC,1).EQ.3)ACLASS='C'
```

```
      IF(ICUE(IC,1).EQ.4)ACLASS='D'
      IF(ICUE(IC,1).EQ.5)ACLASS='E'
      IF(ICUE(IC,1).EQ.6)ACLASS='F'
      IF(ICUE(IC,1).EQ.7)ACLASS='G'
      DO 2000 IH=1,1
      H=HA
      IF(IH.EQ.2)H=0
      IF(IH.EQ.3)H=100
C     ..............DETECTOR LOOP..................
       DO 1900 IN=1,9
       TAU=PHI(IN)
       RES(IN,1)-TAU
C
C     ..............ENERGY LOOP......................
        DO 1800 IEN=1,3
        RSPMAX=1E-15                          !MAXIMUM RESPONSE
        DRESP=0                       !INTEGRAL VALUE
        XLNE=ALOG(E(IEN))
        XMU=EXP(U(1)+XLNE*(U(2)+XLNE*U(3)))         !ATTENUATION COEFFIC.
        I=1                           !LOWER ENERGY FIT
        IF(E(IEN).GT.200)I=4                  !USE HIGHER ENERGY FIT
        A1=A11(I)+XLNE*(A11(I+1)+XLNE*A11(I+2))    !BUILD-UP
        A2=A22(I)+XLNE*(A22(I+1)+XLNE*A22(I+2))    !FACTOR
        A3=A33(I)+XLNE*(A33(I+1)+XLNE*A33(I+2))    !COEFFICIENTS.
        I=1
        IF(E(IEN).GT.400)I=4
        XMUA=EXP(UA(I)+XLNE*(UA(I+1)+XLNE*UA(I+2)))          !ABSORB. COEFF.
C
C     ..  ...... X LOOP .............. .. ....
         DO 1700 IX = 15, 15000+NXBIN/2, NXBIN
         R=IX
         X=R-RAD*COS(TAU)
         NEGZFL=0
         X1=ALOG(R
         PY=PYK(1,NCLASS)+(XX-X1)*PYK(2,NCLASS)+(XX-X1)*(XX-X2)*PYK(
     1   3,NCLASS)+(XX-X1)*(XX-X2)*(XX-X3)*PYK(4,NCLASS)
         PZ=PZK(1,NCLASS)+(XX-X1)*PZK(2,NCLASS)+(XX-X1)*(XX-X2)*PZK(
     1   3,NCLASS)+(XX-X1)*(XX-X2)*(XX-X3)*PZK(4,NCLASS)
         SIGMAY=EXP(PY)
         SIGMAZ=EXP(PZ)
         NDELY=SIGMAY/5
         NDELZ=SIGMAZ/5
         IF(NDELY.LT.5)NDELY=5
         IF(NDELZ.LT.2)NDELZ=2
C
C    ... ............. Z LOOP...................
          DO 1600 IZ=NDELZ/2, 400+NDELZ/2, NDELZ
          Z=IZ
           DO 1500 JJ=1,2
           IF(NEGZFL.NE.0.AND.JJ.EQ.2)GO TO 1600   !BELOW GROUND
           IF(JJ.EQ.2.AND.Z.GT.H)GO TO 1500                  !SET NEGZFL
           IF(JJ.EQ.2)Z=-Z
           NEGYFL=0                         !RESET NEGATIVE Y FLAG
           GZ=EXP(-(Z*Z)/(2*(SIGMAZ**2)))+EXP(-((Z+2*H)**2)/(2*
```

```
        1      (SIGMAZ**2)))
C
C
C........................Y LOOP......................
            DO 1500 IY=NDELY/2, 15000+NDELY/2, NDELY
            Y=IY
            CONC=(1/(2*3.1416*SIGMAY*SIGMAZ))*GZ*
        1   EXP((-(Y**2)/(2*(SIGMAY**2))))
             DO 1490 II=1,2
             IF(NEGYFL.NE.0.AND.II.EQ.2)GO TO 1500
             IF(II.EQ.2)Y=-Y
             DISTSQ=(ABS(RAD*SIN(TAU))-Y)*(ABS(RAD*SIN(TAU))-Y)+X*X+
        1    (Z+H)*(Z+H)
             DIST=SQRT(DISTSQ)
             XMPF=DIST*XMU
             BUF=1+A1*ALOG(XMPF)*(A2+ALOG(XMPF)*A3)
             IF(BUF.LT.1)BUF=1.0
             EXPO=EXP(-XMPF)
             RESP=(CONC*BUF*EXPO)/(12.566*DISTSQ)
D       TYPE 5000 IX,IY,IZ,IEN,IN,RESP,RSPMAX
D5000 FORMAT(' ',5(2X,I4),2E12.5)
             DRESP=DRESP+RESP*NXBIN*NDELY*NDELZ
C......................CHECK SIZE......................
             IF(RESP.GT.RSPMAX)GO TO 1480              !SET NEW RSPMAX
             IF(RESP.EQ.0)GO TO 1440                   !WE'RE OUT OF PLUME
             IF(RESP.GE.RSPMAX/2000.)GO TO 1490       !OK...GO ON
             IF(IZ.EQ.NDELZ/2.AND.IY.EQ.NDELY/2)GO TO 1790          !DONE
             IF(Y.LT.0)GO TO 1460 !NO MORE NEGATIVE Y AT THIS Z
             IF(IY.EQ.NDELY/2)GO TO 1700               !NEXT X VALUE
             GO TO 1590                                !NEXT Z VALUE
 1440        IF(IY.EQ.NDELY/2)GO TO 1590               !NEXT Z VALUE
             GO TO 1700                                !NEXT X VALUE
 1460        NEGYFL=1                           !SET NO -Y VALUES FLAG
             GO TO 1500                         !FINISH Y LOOP
 1480        RSPMAX=RESP                        !NEW MAXIMUM VALUE
 1490        CONTINUE                           !Y INTERNAL LOOP
 1500       CONTINUE                            !Y LOOP
           GO TO 1590
 1580      NEGZFL=1                             !SET FOR NO Z VALUES BELOW GROUND
           GO TO 1600                           !NEXT Z VALUE
 1590      CONTINUE                             !Z INTERNAL LOOP
 1600     CONTINUE                              !Z LOOP
 1700    CONTINUE                       !X LOOP
 1790   RES(IN,IEN+1)=DRESP*E(IEN)*XMUA*1.97
 1800   CONTINUE                                !ENERGY LOOP
 1900  CONTINUE                         !DETECTOR LOOP
C
C.....................PRINT RESULTS......................
       WRITE(6,101)RAD,H
       WRITE(6,99)IC
       WRITE(6,105)ACLASS
       WRITE(6,98)NXBIN
       WRITE(6,104)
       WRITE(6,102)
         DO 100 I=1,9
```

```
               C=(-1.7918*(RES(I,2)-RES(I,3))+1.1394*(RES(I,3)-RES(I,4)))/
            1  (-5.9831)
               B=(RES(I,2)-RES(I,3)+11.2844*C)/(-1.1394)
               A=RES(I,2)-4.382*B-19.2022*C
      100      WRITE(6,103)I,(RES(I,J),J=1,4),A,B,C
     2000   CONTINUE                 !RELEASE HEIGHT LOOP CLOSE
     3000   CONTINUE                 !CALCULATION LOOP CLOSE
      C
            CLOSE(UNIT=6)
      C
        2   FORMAT('$NUMBER OF SAMPLES ? ')
        5   FORMAT('$RADIUS OF DETECTOR CIRCLF (METERS)? ')
       10   FORMAT(F10.0)
       15   FORMAT(A4)
       20   FORMAT(I2)
       30   FORMAT('$STACK OR RELEASE POINT HEIGHT (METERS) ? ')
       35   FORMAT('$STABILITY CLASS [A-G]? ')
       40   FORMAT('$X BIN LENGTH : ')
       98   FORMAT(' ',5X,'X BIN LENGTH = ',I3)
       99   FORMAT('0',6X,'CALCULATION NUMBER ',I2)
      101   FORMAT('1',///,' ',20X,'S U M M A R Y   O F   D E T E C T O R
           1R E S P O N S E   T O   P L U M E',///,' ',5X,'RADIUS OF
           2 DETECTOR CIRCLE = ',F8.2,' METERS',/,' ',5X,'HEIGHT OF RELEASE
           3 POINT = ',F7.3,' METERS')
      102   FORMAT('0',/,' ',6X,'DETECTOR',7X,'ANGLE',18X,'ENERGY (KEV)'
           1,/,'$',19X,'(RADIANS)',6X,'80',16X,'250',16X,'1500',10X,'A',
           28X,'B',8X,'C',/,' ',80('-'),///)
      103   FORMAT(' ',8X,I2,T21,F7.3,T30,3(1PE12.5,7X),3(2X,1PE12.5))
      104   FORMAT('0',20X,'DETECTOR RESPONSES TO PLUME (R/HR)/(CI/SEC)',//)
      105   FORMAT(' ',5X,'STABILITY CLASS = ',A4)
      C
            END
```

APPENDIX D

ESTIMATED NOBLE GAS RELEASE RATES OF TMI-2 FROM TDR-TMI-116

ESTIMATED NOBLE GAS RELEASE RATES OF TMI-2 FROM TDR-TMI-116

Time	Average Release Rate (μCi/s)**				
	^{133}Xe	^{133m}Xe	^{135}Xe	^{135m}Xe	^{88}Kr
400					
500					
600	0	0	0	0	0
700					
800					
900	0.98+05*	0.94+03	0.10+05	0.40+04	0.55+04
1000					
1100	0.58+07	0.75+05	0.90+06	0.26+06	0.27+06
1200					
1300	0.74+07	0.94+05	0.12+07	0.26+06	0.21+06
1400					
1500	0.79+08	0.98+06	0.14+08	0.22+07	0.13+07
1600					
1700					
1800	0.93+08	0.79+06	0.12+08	0.13+07	0.51+06
1900	0.47+08	0.11+07	0.16+08	0.16+07	0.57+06
2000	0.16+08	0.38+06	0.54+07	0.49+06	0.15+06
2100	0.52+08	0.12+07	0.17+08	0.14+07	0.39+06
2200	0.11+09	0.26+07	0.34+08	0.27+07	0.63+06
2300					
2400	0.18+09	0.25+08	0.25+08	0.18+07	0.32+06
0100					
0200	0.32+08	0.38+06	0.43+07	0.25+06	0.32+05

* 0.98+05 means 0.98×10^5

** Release rates are averages for the corresponding hour and previous hours of assumed constant R(t).

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