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AEC Research and Development Report

TECHNOLOGICAL CONSIDERATIONS IN EMERGENCY INSTRUMENTATION PREPAREDNESS

Phase II-A - Emergency Radiological and Meteorological Instrumentation Criteria for Reactors

MAY 1972

BNWL-1635

PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
U.S. ATOMIC ENERGY COMMISSION
Under Contract AT(45-1)-1830

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.95

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FOREWORD

The Atomic Energy Commission, through its Division of Operational Safety, has contracted with the Battelle-Northwest Laboratory to conduct a study and develop technical criteria for determining the adequacy of instrumentation for use in radiological emergencies, abnormal occurrences and accidents. The program is responsive to the recommendations of the AEC Advisory Committee on Reactor Safeguards regarding accidents involving the release of radioactivity. The work has been progressing in close collaboration with the AEC's Regulatory Divisions. A technical steering committee was established comprising representation from the Divisions of Operational Safety, Reactor Licensing, Reactor Development, the Universities Division, Richland, and the Environmental Protection Agency. This committee provides surveillance and technical direction and assures that the overall needs of the program and associated objectives are met. As a first step, the Battelle-Northwest Laboratory reviewed current practices at a number of Commission owned and licensed facilities. Results of this review were approved and reported in BNWL-1552, "Technological Considerations in Emergency Instrumentation Preparedness, Phase I - Current Capabilities Survey". This report provides a summary of the "Emergency Radiological and Meteorological Instrumentation Criteria for Reactors" which has been developed during the first portion of the Phase II study.

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I. INTRODUCTION AND SCOPE

This report is intended to serve as a guideline for both reactor facility operators and regulatory agencies and it is intended to set a rational pattern for the development and improvement of emergency instrumentation.

In the design of reactor cores and control systems, effective use is made of physics parameters and tested mechanical and electronic elements to prevent nonstandard operation. Engineered safeguard systems are provided to limit the effects of an unlikely loss of control to within the reactor facility. The licensing process makes certain that the design criteria are satisfied and that operating procedures are followed. The application of these layered multiple safety factors makes it highly improbable that large quantities of radioactive material will be accidentally released to the environment. It is prudent, nevertheless, to consider possible consequences of such releases and examine in some detail instrumentation and procedures for: (1) quickly detecting the occurrence of a release, (2) quickly assessing the intensity and direction the release takes, and (3) estimating the impact of the release on the environs. All three requirements need to be fulfilled if the operators of a nuclear facility are to be well prepared to determine the potential and actual consequences of such a serious but very low probability event.

Few studies have called out specific criteria for performance and placement of radiological and meteorological instrumentation useful for characterizing the emergency situation. Most publications on radiological emergencies deal primarily with plans and procedures, action levels, and environmental consequences, and at most mention instrumentation performance, needs, and related criteria in only very general terms.

A study has been undertaken to investigate current instrumentation capability for dealing with the accident situation. The study was performed as an integral part of a program to identify the need and develop emergency instrumentation criteria for use in AEC operations. The complete study on emergency preparedness requirements, which is supported by the AEC with guidance provided by other federal agencies, is conveniently subdivided into three phases:

1. A survey of both private industry and AEC contractors to determine their instrumented capability for meeting a radiological emergency.
2. Development of suitable criteria on emergency instrumentation preparedness for nuclear reactors, fuel fabrication plants, fuel reprocessing plants and major isotope laboratories.
3. Implementation of research and development identified in the previous phase to aid in the development of needed instrumentation and provide methods and facilities for evaluation, calibration, and certification of emergency instrumentation.

The first phase of this study was completed in 1970 and the results of this portion were reported in BNWL-1552, "Technological Considerations in Emergency Instrumentation Preparedness, Phase I - Current Capabilities Survey," dated January 1971.[1] The Phase I report comprises the results of questionnaires and inspections relative to emergency instrumentation preparedness at 25 major nuclear sites, including licensed power reactors, fuel reprocessing plants, and USAEC contractor sites. Emergency radiological instrumentation, as suspected by Bell and others,[2] was found to be deficient to some degree at all facilities visited, and in some cases, no instrumentation was provided specifically for the emergency situation.

The second phase of the study is the development of sound technical and operational criteria for emergency instrumentation and identification of research and development areas. Reactors, plutonium and uranium fuel fabrication plants, fuel reprocessing plants, and major isotope laboratories will be considered individually in the development of these criteria. Criteria for several instrument and instrumentation systems will be included for each of the nuclear facility types:

- Liquid and gaseous radiological effluent monitoring instrumentation, both within the facility and in the environs.
- Ambient radiation monitoring instrumentation.
- Portable radiological monitoring instrumentation.
- Meteorological instrumentation, both for synoptic and predictive purposes.

The development of technical criteria pertaining to communcations equipment, emergency control center instrumentation, and evaluation of emergency instrumentation is considered to be a separate phase of the study and will be described in a later document. Specifically excluded from consideration are process monitoring, personnel dosimetry, and criticality dosimetry and instrumentation per se. Also excluded from these studies are consequences, operations and planning.

The initial work on Phase II was limited to nuclear reactors and the results of the work are detailed in this report. Included are criteria for instrumentation for determining the nature and extent of a radiological incident immediately after its occurrence. This report seeks to establish emergency instrumentation criteria for the contemporary reactor, in consonance with what is needed, reasonable, and achievable with the current state-of-the-art, while at the same time identifying areas in which additional study is indicated. It should not be inferred that either these proposed criteria or techniques represent the only satisfactory solution. What has been done is to point out what appears to be achievable by more completely exploiting current capabilities.

Before criteria for reactor emergency instrumentation could be developed, it was necessary to establish the maximum fission product inventory which could be involved in an accident, and also to make certain assumptions about the fraction of the inventory which might escape from the core. Once the fission products were characterized, instrumentation requirements for quickly assessing the release and predicting the trajectory and airborne concentration downwind were defined.

Based on the quantity and characterization of airborne fission products which could escape, guides to instrument selection are given along with criteria for performance and placement, and some techniques presented for estimating the magnitude of the release. Instrumentation for meteorological parameter measurement is considered in detail because of the important role such measurements will play in determining the direction of flow and dispersion in the atmosphere, and in the initial response by monitoring personnel.

II. THE REACTOR AND ACCIDENT POTENTIAL

II.A. ACCIDENT BOUNDS

Reactors present a diversity of potential accident sources, ranging from zero power, uncontained research reactors to power reactors containing large inventories of fission products. Approximately 250 radionuclides are produced by the fission process, and the specific composition of the inventory is a complex function of fuel, core parameters, operating time, and decay time, among others. The total inventory or quantity of radioactivity is basically a function of three parameters - operating time, decay time, and power level. Power level and the quantity of radioactive material are directly proportional. The relationship of quantity of radioactive material to operating and decay time are shown in Figure 1 for a typical thermal reactor fuel (initial fission ratio ^{239}Pu: ^{235}U = 0.0689) as calculated with the RIBD computer code.[3] Assuming a constant release fraction, operating power level variations of 100 among various reactors, and decay times of only up to 10 hours, the radioactivity involved may range over eight orders of magnitude. Hence, emergency monitoring instrumentation may well be required to cover a wide range of radiological conditions.

To provide perspective, an accident potential classification - High, Medium or Low - based on severity was established in Phase I for nuclear facilities. The classification postulates no mechanism nor does it consider the probability for occurrences; it takes into account the total inventory of radioactive materials and the fraction released to the containment vessel. Reactors may be categorized by type of use into this broad classification scheme for severity potential without the need for precise definition or boundaries, as shown:

Severity Potential	Reactor Use
High	Power, Production
Medium	Test
Low	Research, Critical Facility, Training

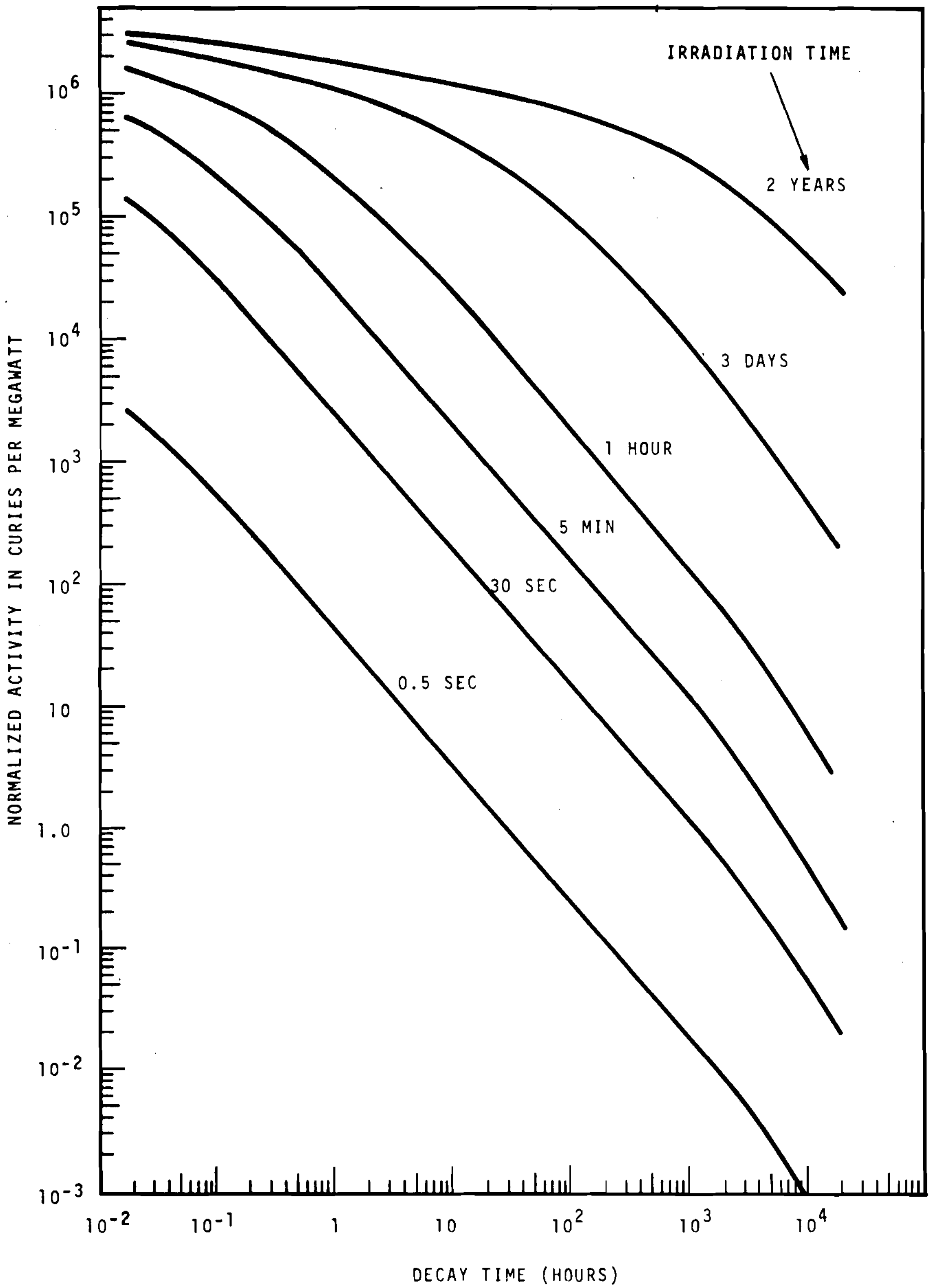


FIGURE 1. Effect of Irradiation Time on Activity - Decay Relationship - All Fission Products

In other words, there are three discrete groups of reactors based on potential severity of accident, and this fact will influence emergency instrumentation requirements and selection.

For reactors in the Low Severity Potential group, the consequences of the maximum accident will be considerably less severe from a radiological point of view. An upper limit to the inventory of radionuclides available in the core of these reactors might be that equivalent to a few megawatt years produced at power levels of <1 MW, or roughly three orders of magnitude less than that potentially available in the Medium Severity Potential reactors. Although reactors in this group may have less constrictive controls and containment features, the relatively small radioactive material inventories involved preclude their further consideration in this phase of the study. It is planned to consider these facilities further in future studies which deal with major isotope laboratories.

For reactors with Medium and High Severity Potential, the maximum accident case, which determines the upper range of the radiological instrumentation, is taken to be that of DiNunno, et al.[4] This is modified to assume an operating power level of 3500 MW(t) for one year. An estimated 15% of the total fission product inventory is released to the containment vessel, this fraction containing 100% of the noble gases, 50% of the halogens, and 1% of the remaining fission products. In addition, only 50% of the iodines released to the containment vessel remain available for release to the atmosphere.

DiNunno assumed a specific leak rate from the containment. However, for the purpose of this study no assumptions were made regarding rate of leakage, rather it was assumed that the instruments must be capable of detecting and accounting for the radionuclides whether they remained in the containment or were released to the environs. In the latter case no leak rate was specified.

Establishing a lower level or minimum accident case is more difficult than for the maximum accident, since virtually any unplanned release of radioactive materials, however small, can be considered an accident. Considering only uncontrolled radioactive material, a spill or release of only a few curies may be significant and result in activation of the emergency protocol. Similarly, if criticality is considered the criterion, from review of the literature on reactor and critical assembly accidents, a lower limit of about 10^{16} fissions from a nuclear excursion with fresh fuel appears to be the practical minimum.[5-7]

There are, however, radioactive material release situations other than a nuclear excursion which could create an emergency situation. In general, these will involve mixed fission products, and, for the purposes of defining a "minimum accident" or lower limit of detection capability for the emergency instrumentation, a release over a short time period roughly equivalent to 10^3 times the average annual release rate will be assumed. This assumption in no way implies that lesser releases would not be monitored, nor characterized, or otherwise handled with speed and concern. It is intended that this lower level will overlap with operational monitoring instrumentation used routinely for detection and quantification of lower level or routine releases.

Most reported reactor accidents of sufficient consequence to be reported in the literature[4-6] fall within the range cited above, and most if not all Design Basis Accidents postulate radioactive material releases below the upper limits cited.

The discussion above is germane primarily to airborne releases, and indeed, the overwhelming consideration is given to the airborne release of radioactive material. Releases of radioactive material via liquid media constitute a second but more restricted means of injection of radioactive material into the environment. In many accident situations, large quantities of heat will be generated, precluding liquid releases <u>per se</u>. However, depending on the type of reactor, numerous mechanisms resulting in liquid carriage of released radioactive material can be postulated. Virtually all of these fall within the range postulated above. Hence, in part for simplicity and consistency, the limits discussed above should serve adequately for the waterborne or liquid release case. It should be kept in mind that in a major accident, the airborne release will be the first consideration.

II.B. CHARACTERIZATION OF IONIZING RADIATION FROM A REACTOR ACCIDENT

It is convenient to characterize the inventory or source in terms of broad groups based on physicochemical properties. Several such groupings appear in the literature, along with estimates of fraction of radioactive material released. A partial review of the literature [3-29] on fission product behavior and release in accident or simulated accidents leads to the three group classification given below in Table 1. The release fractions cited for both air and water are conservative and consistent with values generally assumed for safety analyses and design basis accidents.

TABLE 1. Fission Product Classification

Group	Constituents	Characteristics
Noble Gases	Kr, Xe	Short half-lives. Essentially chemically inert (Group VIII). Primarily external exposure hazard. Assumed airborne release fraction = 1.0. Liquid release fraction 0.5.
Halogens	I, Br	High chemical reactivity (Group VII). Radioiodines primary hazard with biological localization in thyroid. Bromines are precursers of radiostrontiums which are long-lived bone seekers. Assumed airborne release fraction = 0.25.[a] Liquid release fraction = 0.5.
Solids	All Remaining Fission Products	Moderate chemical reactivity. Primarily internal hazard. Assumed airborne and liquid release fraction = 0.003.[b] Liquid release fraction = 0.01.

a. The product of a core inventory release fraction of 0.5 and a plate-out correction factor of 0.5.
b. The product of a core inventory release fraction of 0.01 and a plate-out correction factor of 0.3.

Using the libraries and data from the RIBD and ISOSHLD-III computer programs[3,30,31] and a general literature review, an examination was made of the fission product inventory to ascertain if any unique or significant characteristics or commonality of nuclides could be determined which would simplify or improve detection capabilities. Ratios of specific nuclides, beta and photon energy distributions, and similar characteristics were looked at as a function of both operating and decay times.

Several useful facts were revealed by this evaluation. With the exception of a burst or criticality case, the fractional radioactivity of each of the groups shown in Table 1 is essentially constant within the limits of decay and operating times shown in Figures 2, 3, and 4. Of particular interest is the noble gas fraction, which is the major constituent of a release and has several radionuclides emitting photons in the region of 2 to 3 MeV.

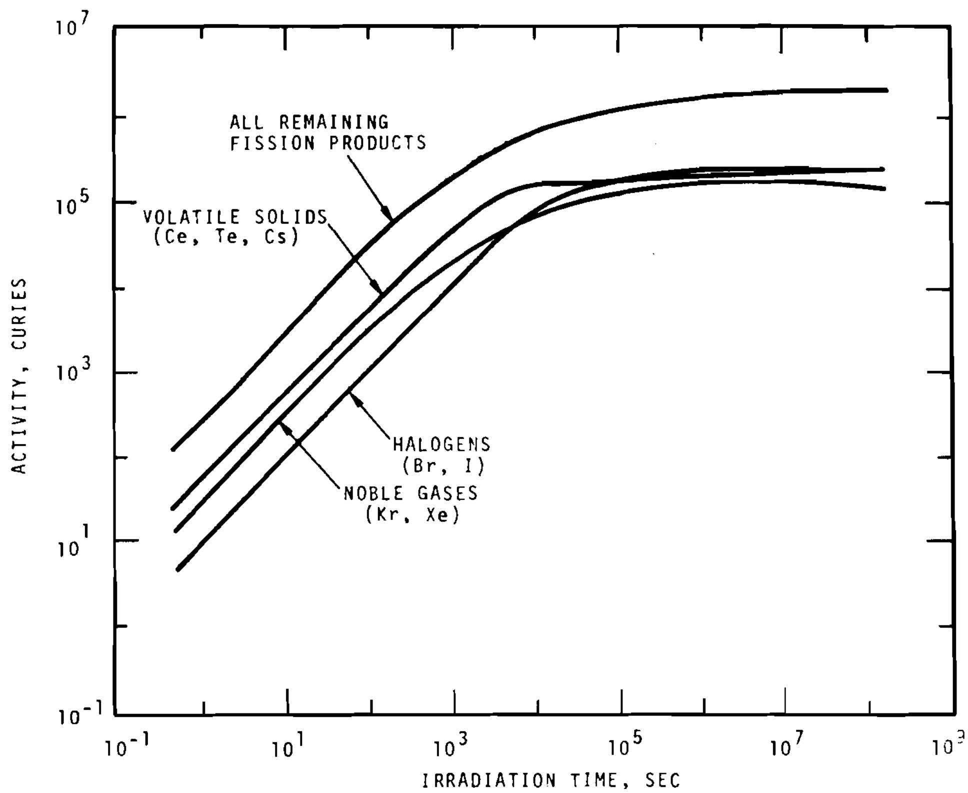


FIGURE 2. Distribution of Fission Products as a Function of Irradiation Time at 20 Minutes After Shutdown

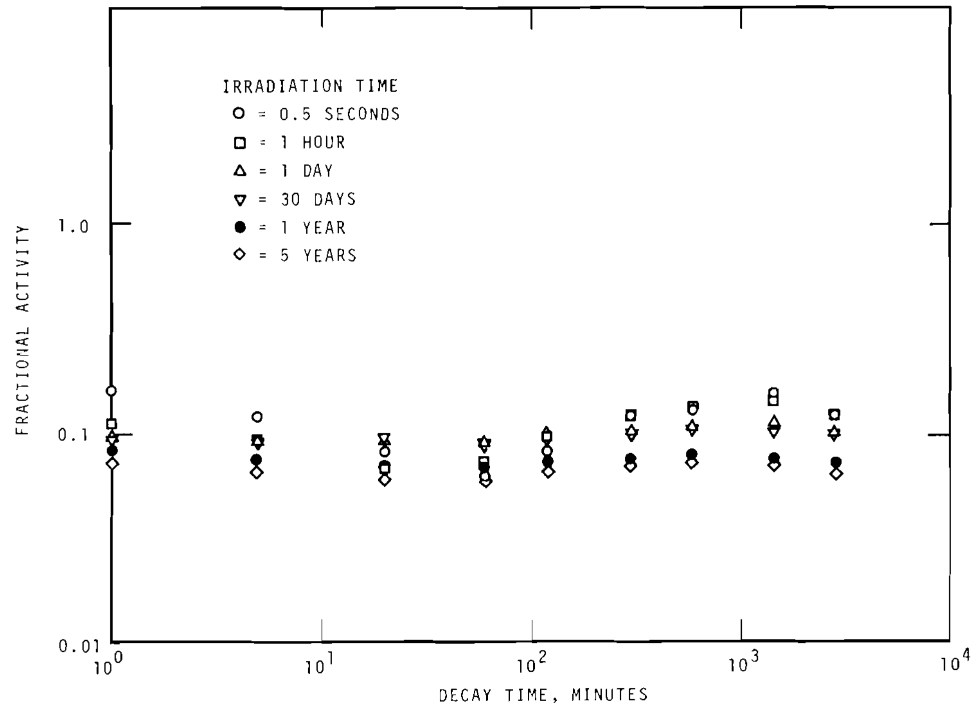


FIGURE 3. Effect of Irradiation Time on Fractional Activity of Noble Gases at Selected Decay Times

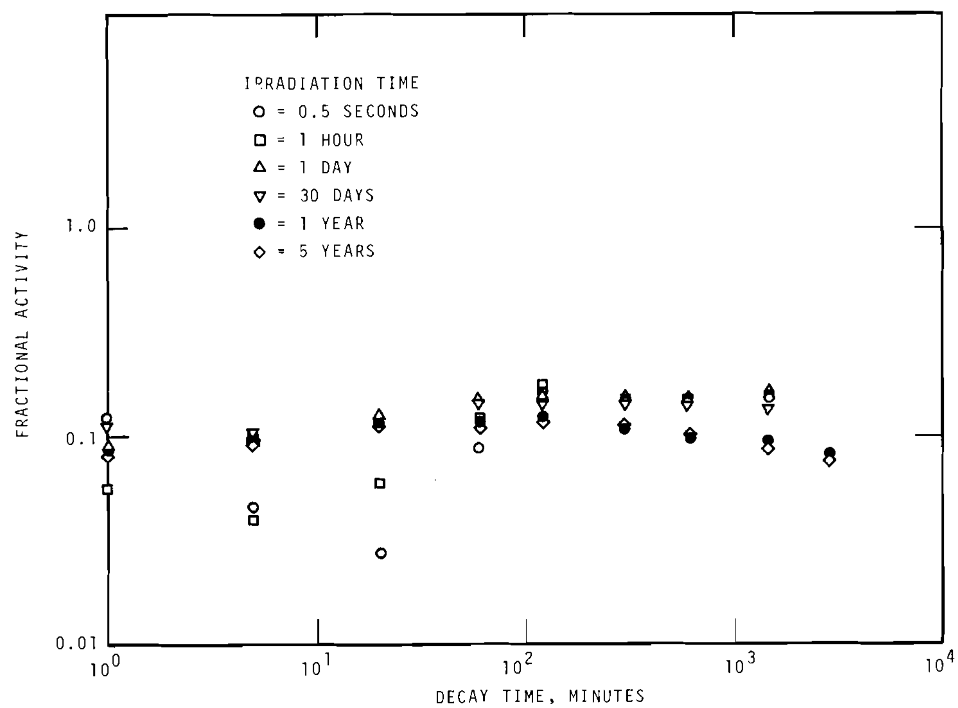


FIGURE 4. Effect of Irradiation Time on Fractional Activity of Halogens at Selected Decay Times

Examination of Figure 3 shows the constancy of the radioactivity fraction for the noble gases. For decay times from one minute to one day, the fractional radioactivity from the noble gases is approximately constant at about 10%. Since these have the greatest release fraction to the atmosphere, the noble gases would be expected to provide well over half of the airborne radioactivity released following an accident. The remainder of the radioactivity is mostly from the halogens, which also have a constant radioactivity fraction (Figure 4).

Although differences in gross radioactivity or isotopic composition will occur as a result of reactor type, use, fuel and other core parameters, they will be ignored since they are small in comparison to effects of power level and operating and decay time. The major contributors and their energies are given in Table 2 below.

TABLE 2. Photon Emission in 2 to 3 MeV Range by Noble Gases and Daughters

Nuclide	Accumulated Fission Yield, %	Half-Life	Photon Energy, MeV	Intensity Photons Per Dis.	Comments
^{87}Kr	2.6	76 min	2.57	0.35	
^{88}Kr	3.6	2.8 hr	2.19 2.40	≤0.18 0.35	
^{88}Rb	3.6	18 min	2.68	0.023	^{88}Kr daughter
^{89}Rb	4.8	15 min	2.20 2.59	0.14 0.13	^{89}Kr daughter
^{90}Kr	5.8	33 sec	2.48	0.04	Direct fission product only
^{138}Xe	5.7	18 min	2.02	<0.01	
^{138}Cs	5.7	33 min	2.21 2.63	0.18 0.09	^{138}Xe daughter
^{140}La	6.4	40 hr	2.53	0.03	Direct yield excluded

NOTE: Yield data from (32); half-life, energy and intensity from (33).

Table 2, shows that most of the photons from the noble gases, halogens, and their daughters that have energies greater than 2 MeV are associated with the decay of the radiokryptons and daughters. The aggregate contribution from radioxenons and daughters is relatively small, as is the contribution from the halogens. (Of the latter, only ^{84}Br and ^{136}I emit photons in this energy region with any significant abundance.) Hence, the photons with energies greater than 2 MeV result primarily from radiokrypton decay. The fraction of radiokryptons is constant for decay times up to about 10 hours, suggesting measurement of photon energies greater than 2 MeV as a possible means of quantification within the first few hours after the accident.

Using the atmospheric release fraction data from Table 1 and the fractional radioactivity, the approximate composition of the airborne inventory of radioactive materials can be calculated as shown in Table 3.

TABLE 3. Atmospheric Radioactive Materials Characteristics

Category	Approx. Fraction of Activity in Reactor Core	Approx. Core Release Factors	Approx. Plate-Out Correction Factors	Relative Fraction Airborne in Containment Vessel
Noble Gases	0.1	1.0	1.0	0.8
Halogens	0.1	0.5	0.5	0.2
All Remaining Fission Products	0.8	0.01	0.3	0.02

From Table 3, it can be seen that practically all of the airborne radioactivity will be from noble gases and halogens. As previously pointed out, the noble gases, and in particular, the radiokryptons and daughters, produce most of the photons with energies greater than 2 MeV.

III. EMERGENCY INSTRUMENTATION REQUIREMENTS

Several types of emergency instruments or instrumentation systems should be provided to characterize the severity and extent of the accident and to aid in the protection of operating personnel and personnel living in the environs. The instruments should be capable of characterizing the release to the containment vessel and the radiological problem associated with re-entry. Instrumentation also should be available to estimate the amount of radioactive material released to the environs either via normal effluent channels or unanticipated breech of the containment. Meteorological instrumentation should provide necessary data to determine the direction the cloud will follow and the necessary parameters to permit rapid calculation of the consequences within a 10 mile radius of the plant using a diffusion model appropriate to the site. Additionally, it may be necessary to provide instrumentation to aid in early direct assessment of the environmental consequences in the same area. Finally, survey instrumentation is necessary to supplement fixed instrument systems, to make radiological measurements at locations not covered by fixed instrumentation, and to aid in protection of operating personnel during their efforts to stabilize the emergency.

Specific instruments or instrument systems that are either required or recommended for coping with an emergency are described below. Sections IV and V describe the characteristics of these instruments and systems and Section VI contains specific performance criteria. Typical reactor emergency instrumentation systems are illustrated in Figure 5.

III.A. AIRBORNE RADIOACTIVE MATERIAL MEASUREMENT IN THE CONTAINMENT VESSEL

Direct measurement of the airborne radioactive material in the containment vessel following a high radiation alarm or known incident is necessary to evaluate the nature and amount of airborne material potentially available for leakage or which is leaking to the environs. While the sampling and measurement from contained volumes will not of itself permit evaluation of a leak to the outside, the data will be valuable for reconstructing the sequence of events and in corroborating and supplementing

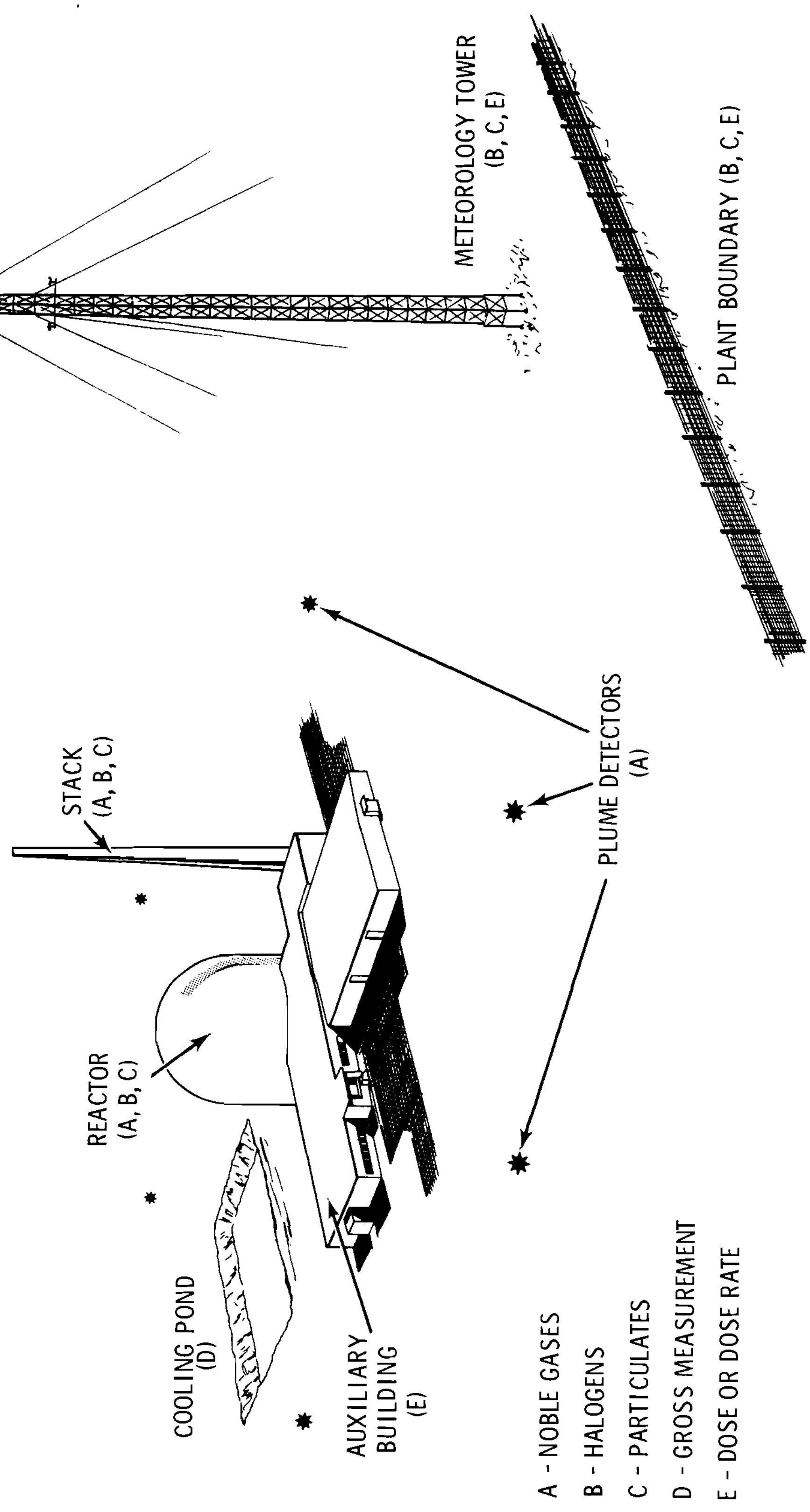


FIGURE 5. Reactor Emergency Instrumentation Systems

other input into the accident assessment. Within minutes of the incident, it could add important data regarding the seriousness of the situation. In addition, sampling and laboratory analysis could provide a measure of the effectiveness of the engineered safeguards and the natural removal processes and therefore provide an indication of the composition of radioactive material released or available for release to the outside. The information will also be of value with respect to re-entry into the containment vessel.

Obtaining representative measurements from a large volume at a single location requires that the gases and particles be well mixed in the vessel. The particular circumstances surrounding the accident will alter the degree of uniformity of mixing, and stagnant regions will likely be present. However, studies conducted at the Containment Systems Test Facility at Battelle-Northwest show that mixing was rapid in a large vessel filled with steam due to thermal convection.[19-21] Although a detailed study has not been conducted on a vessel as large as 2×10^6 cubic feet, it is likely that over a period of minutes, reasonably uniform mixing will occur.

Assuming an accident equivalent to the maximum postulated in Section II, and a containment volume of 5.7×10^{10} cm^3 (2×10^6 ft^3), the maximum concentration of airborne fission products in the contained volume will be of the order of 5.9×10^{-3} Ci/cm^3, distributed as 4.4×10^{-3} Ci/cm^3 noble gases, 1.1×10^{-3} Ci/cm^3 halogens, and 3.5×10^{-4} Ci/cm^3 solids. The minimum concentration in the containment volume is taken to be 10^{-7} of the maximum above.

III.B. AMBIENT DOSE RATE MEASUREMENT IN THE CONTAINMENT VESSEL AND BUILDING

Ambient dose rate monitoring or area monitoring with fixed instrumentation will be of value in the immediate postaccident situation. Remote area monitors (RAMs) are useful primarily as indicators of the ambient radiation field in the reactor containment vessel and building, and this data can be useful for decisions regarding life or property saving measures.

Data from RAMs may also be of value in determining changes in the radiation environment, including additional activity releases or radioactive decay. However, the data obtainable are quite limited, particularly in view of the fixed nature of the detector, and the possibility that the detectors may have been subjected to temperature or pressure extremes. Moreover, the physical location of the detector may be such that an inaccurate portrayal of the radiation field is given.

Area monitors are usually provided in a nuclear facility to meet legal or contractual requirements and to provide an alarm when ambient radiation levels exceed predetermined levels. Virtually all such instruments are designed as exposure rate meters, and some have an effective lower level energy cutoff near 100 keV. While these detectors may be suitable for routine monitoring situations or for warning purposes, they ignore the major component of the ambient radiation field associated with unshielded fission products, namely the beta radiation and associated low energy bremsstrahlung. Beta to photon dose rate ratios can be as great as 30 to 1 under some circumstances, and if the RAM system is to be used to evaluate re-entry possibilities, it should have capability of beta measurement. Similarly, low energy photon measurement capability must be provided, because both bremsstrahlung and scatter can contribute appreciably to the dose.

III.C. RADIOACTIVE MATERIAL MEASUREMENT TO THE POINT OF RELEASE

III.C.1 Stack Effluent

Radioactive material may be released to the environs through the reactor building ventilation system as a result of an accident. Such a release could occur whether or not containment has been breeched. Ventilation air and air in intimate contact with radioactive material can sweep radioactive gases and some small particles through any cleaning or treatment processes, and finally to the exhaust point. In nearly every case the exhaust point will be a stack ranging from some tens of feet to several hundred feet tall, resulting in dilution and dispersion before the materials reach ground level. In its passage through the ventilation system, the effluent may be treated by filtration, liquid scrubbing, adsorption beds, or a combination of these and other air cleaning techniques; but in a serious accident, these engineered safeguards could fail structurally as a result of overloading or other mechanical means.

The stack release may involve some or all of the fission products including noble gases, halogens and particulates released to the containment vessel and in concentrations which could approach those found in the containment vessel depending on the effectiveness of the cleanup processes. Although stack monitoring instrumentation may be designed to detect the same materials, the instrumentation may be as much as 10^6 too sensitive.

III.C.2. Liquid Effluent

Although circumstances can be postulated which will result in uncontained liquid releases without concomitant air releases, the liquid release situation is analagous to the stack release in that the liquid is channeled through a piping system before release. Hence in virtually all situations, including the rupture of a main pipeline, the liquid can be monitored within an enclosed volume. While a large uncontrolled spillage or release of highly contaminated liquids could be postulated, the resultant airborne or ambient radiation hazards would be of greater immediate concern.

Liquid monitoring thus is primarily a problem of measurement in an enclosed or partially enclosed volume. Although aqueous liquids are the primary consideration, other coolant or moderating liquids such as organics or corrosive liquids may be included if these can be released to the environs in any quantity. Specifically excluded from consideration here are liquid metals or materials normally solid at 25°C.

There are two basic methods for emergency monitoring of liquid effluents: direct measurement of the radioactivity in the liquid and sample withdrawal and analysis. Although the latter can be accomplished by an appropriately designed sampler-monitor, direct measurement permits the most rapid and representative analysis. In addition, direct monitoring may reduce errors associated with sampling, incomplete or inadequate mixing, evaporation or effervescence of dissolved or suspended gases, and radioactive decay. Hence, direct measurement techniques are strongly recommended.

III.D. DETERMINATION OF THE MAGNITUDE AND DIRECTION OF THE PLUME

To effectively apply emergency protective actions against an airborne radioactive material release from a reactor, it is necessary to know the nature, extent and direction of the release, downwind air concentrations, ground deposition, and external dose rates. Data can be either directly obtained or calculated from measurements. To implement emergency plans, these data or estimates should be obtained as soon as possible after the accident.

III.D.1. Radiological Measurements

Measurement within or immediately adjacent to the reactor building, while providing the most rapid data, is unsatisfactory on many grounds. The large inventory of fission products with its subsequent high levels of ambient radiation make detection and quantification questionable. Similarly, thermal shielding and aerodynamic effects from the facility or nearby objects may seriously impair the collection and accuracy of the radiological data. Measurements should be made sufficiently far from the source to minimize or eliminate interferences, while yet providing data representative of the source location. Thus, measurement at some distance external to the reactor building is indicated and the discussion in Section IV will separately consider the necessary radiological and meteorological measurements.

III.D.2. Meteorological Measurements

In the event of a reactor accident resulting in a leak of radioactive materials to the atmosphere, it is necessary to employ real-time onsite meteorological data to provide a realistic estimate of the actual path of travel of the plume and the concentrations in the plume as a function of space and time. This requirement exists on two time scales. The first requirement is to immediately assess the area to be affected by the accident and determine and implement the action appropriate to minimize the direct exposure hazard to individuals within and beyond the plant boundary. The second requirement is to conduct a detailed postaccident analysis to determine the effects of the accident and the action required to protect individuals from indirect exposure.

Whereas preoperational accident analyses are based upon climatological data and result in probabalistic statements of effect, the real-time and postaccident analyses require quick response to a real and singular event. This basic factor places constraints upon instruments, data handling procedures and analysis technique not common to preoperational evaluations. The meteorological criteria recommended in this report are intended to reflect this basic difference, taking into account the state-of-the-art in meteorological instrumentation and diffusion modeling. It should be realized that certain judgements required of the authors might be made differently by others.

A major requirement in establishing common criteria and in implementing them is the recognition that it is not possible to specify criteria that will be optimum for all sites and accident situations. The criteria described are considered minimal requirements. Also, it has been recognized that it is not possible to specify the required number or spacing of wind stations outside of the plant boundary because of topographic variability and complexity of local meteorology. These considerations require the evaluation of meteorological emergency preparedness instrumentation systems on a site-by-site basis. The purpose of such an evaluation would be to determine the compatibility and adequacy of the meteorological system for the implementation of the real-time emergency plan and for conducting an appropriate postaccident analysis at that site.

It is recognized that the data requirements vary with the model(s) selected for estimating diffusion. However, the data requirements identified are intended to avoid placing constraints upon the types of models employed. The accuracy requirements identified for specific types of measurements are those considered appropriate to the models employing that type of measurement. The specification of a specific model(s), and hence data handling and analysis procedures, has not been included within the scope of the present study although it is considered an appropriate and necessary subject for future study. It should be recognized, however, that such a study is contingent upon further definition of operational requirements and procedures.

In Section IV.B. requirements for meteorological data and instrumentation which are considered necessary to provide the information for real-time and postaccident analyses are discussed and the minimum criteria for the system are in Section VI.B.

III.E. RADIOLOGICAL MEASUREMENTS IN THE ENVIRONS

An informal network exists for radiological monitoring in the environs around nuclear facilities, including those systems now coordinated by the Environmental Protection Agency.[34] In general, these stations are not oriented to detection, quantification, and prediction in the early post-accident hours, and are not likely to be appropriately located to be useful. Civil Defense and other governmental emergency teams are also unlikely to be able to provide prompt determination of the extent of the impact on the environs. In some states and communities, however, response may be rapid enough and capability such as to relieve the facility operator of any extended off-site operations. The availability of such assistance or control if required should be detailed in emergency plans for the facility.

Thus, a plan for emergency off-site radiological monitoring must be established, and this is commonly done for reactors as a part of the general safety plan. The design and adequacy of the plan are beyond the scope of this report. The purpose is to provide general criteria for fixed monitoring equipment in the environs, working under the assumption that decisions with respect to specific numbers, locations, and types are peculiar to the individual site and have been predetermined.

Most emergency monitoring in the environs will be accomplished with portable (or mobile) instruments, for it would be forbiddingly expensive to instrument and continuously monitor large areas of the environs. However, a few critical locations can be usefully monitored on a more or less continuous basis, using fixed AC-powered instrumentation. Two basic monitoring systems will be considered: fixed air monitors and ambient radiation monitors.

Continuous water monitoring in the uncontrolled environs is not considered, for in the first 24 hours postaccident there is little probability that data other than from grab sampling will be needed. This assumes that monitoring of the liquid effluents continues in the event of an emergency either at the source or at least within the plant site. A further assumption has been made that unlike an airborne release, the movement of liquid releases can be predicted in advance with some reliability. The ability to do this should be derived from preoperational studies and operational experience.

III.F. AMBIENT RADIATION AND CONTAMINATION SURVEYS

Following a reactor accident, heavy reliance will be placed on portable instruments to obtain first hand information regarding ambient radiation or surface contamination levels both at or near the accident site and in the environs. The information obtained with these instruments may be used as the basis for actions involving rescue of personnel or the protection of health and property. In addition, these instruments may be useful in mapping radiation fields, assisting in contamination control, and even as the means of determining personnel exposed to fast neutrons from a criticality.[35]

The effectiveness of routine off-site sampling stations in providing useful information in the event of an accidental release should not be overlooked. Quick surveys using portable survey instruments of particulate air filters at routine air sample locations may well provide a rapid indication of cloud passage, if there has been a major release of nuclides other than noble gases. In addition, analysis of air filters and readout of dosimeters (relatively inexpensive for broad deployment) even though return to a laboratory may be necessary for data extraction, provide a second order of field data generally obtainable within a few hours following the release.

Integrating devices such as pocket dosimeters, personal alarm dosimeters, self-developing film and thermoluminescent dosimeters with battery operated readout may find application in the field in the early hours after the emergency. Units which provide a cumulative record of exposure or dose along with a predetermined alarm point could be of inestimable value in rescue efforts. Similarly, small, inexpensive dosimeters liberally spread throughout the environs could provide an otherwise unobtainable characterization of a meandering cloud.

Mobile (i.e. mounted in airplanes, motor vehicles, or boats) instrumentation has a place in facility emergency planning, even though the use of specific instruments systems may be appropriate only in certain kinds of emergencies. For example, the use of airplane-mounted instruments (aerial monitors) has been frequently suggested for tracking a radioactive gas cloud, but may be of less value than a boat-mounted instrument for a moderate liquid release. Vehicle-mounted instruments, (road monitors) although less effective than aerial monitors for rapid, wide-area scanning for deposition, are used in routine surveys, and therefore may be more immediately and reliably available in an emergency situation.

Kiefer and Maushart[36] have pointed to five special requirements for emergency survey instrumentation:

- Measure higher dose rates than normal
- Obtain results more quickly than usual
- Make a larger number of measurements than usual

- Carry out measurements in unusual areas, in the open air, in cars, in trucks, or in provisional laboratories
- Use unskilled personnel for making measurements and taking samples.

To these should be added the consideration of the potential use of the instruments - e.g., for evaluating the potential dose to those involved in rescue operations, or for evacuation of a populated area. These factors dictate a need for reliability and accuracy that might not otherwise be required.

IV. EMERGENCY INSTRUMENTATION SYSTEMS CHARACTERISTICS

The required characteristics of Emergency Instrumentation systems which will assure operation under all conditions and provide needed data to cope with the emergency are considered in this section. The specific performance criteria for these systems are presented in Section VI. General criteria for installed radiological systems are presented in Section VI.A.1. and general criteria for gaseous and particulate sampling are presented in Section VI.A.2.

Table 4 presents a summary of the containment vessel release assumptions which were used in this study and the detector range requirements which were developed.

IV.A. PLUME DETECTION

Performance criteria for the Plume Detection Instrument System are presented in Section VI.A.3.a.

IV.A.1. Plume Measurement Method

Section III.D. described the need to provide a capability to determine the amount of material released and the direction it leaves the site. This section describes the technical factors to be considered in choosing and placing the needed radiological instrumentation and interpreting the data. A description of the factors to be considered for the associated meterological instrumentation is included in the following section.

The direction of the plume leaving the reactor building and an estimate of the radioactive material inventory can be determined by use of a circular array of detectors equally spaced around the reactor. The concept of equally spaced detectors has been independently proposed by Henderson,[37] King[38] and Palmer.[39] In the method of Henderson,[37] data from one of a dozen equally spaced air samplers was used along with appropriate meteorological observations and estimates to provide a rapid estimate of the total activity passing a detector. ^{138}Xe was used as the major cloud constituent, although any photon emitter(s) can be monitored

TABLE 4. Summary of Containment Vessel Release Assumption and Detection Range Requirements

	Curies per cm^3		
	Noble Gases	Halogens	Particulates
Containment Vessel Inventory	4.4×10^{-3}	1.1×10^{-3}	3.5×10^{-4}

Air Monitors

	Detection Levels (Curies per cm^3)					
	Noble Gases		Halogens		Particulates	
	Min	Max	Min	Max	Min	Max
Containment Cell Monitor	10^{-9}	10^{-2}	10^{-10}	10^{-3}	10^{-10}	10^{-3}
Stack Monitor	10^{-9}	10^{-2}	10^{-10}	10^{-3}	10^{-10}	10^{-3}
Environs Monitor	-	-	10^{-13}	10^{-8}	10^{-12}	10^{-7}

	Detection Level
Plume Detector	10^{-2} to 10^{3} Ci/meter
Liquid Monitor	10^{-9} to 10^{-4} Ci/cm^3

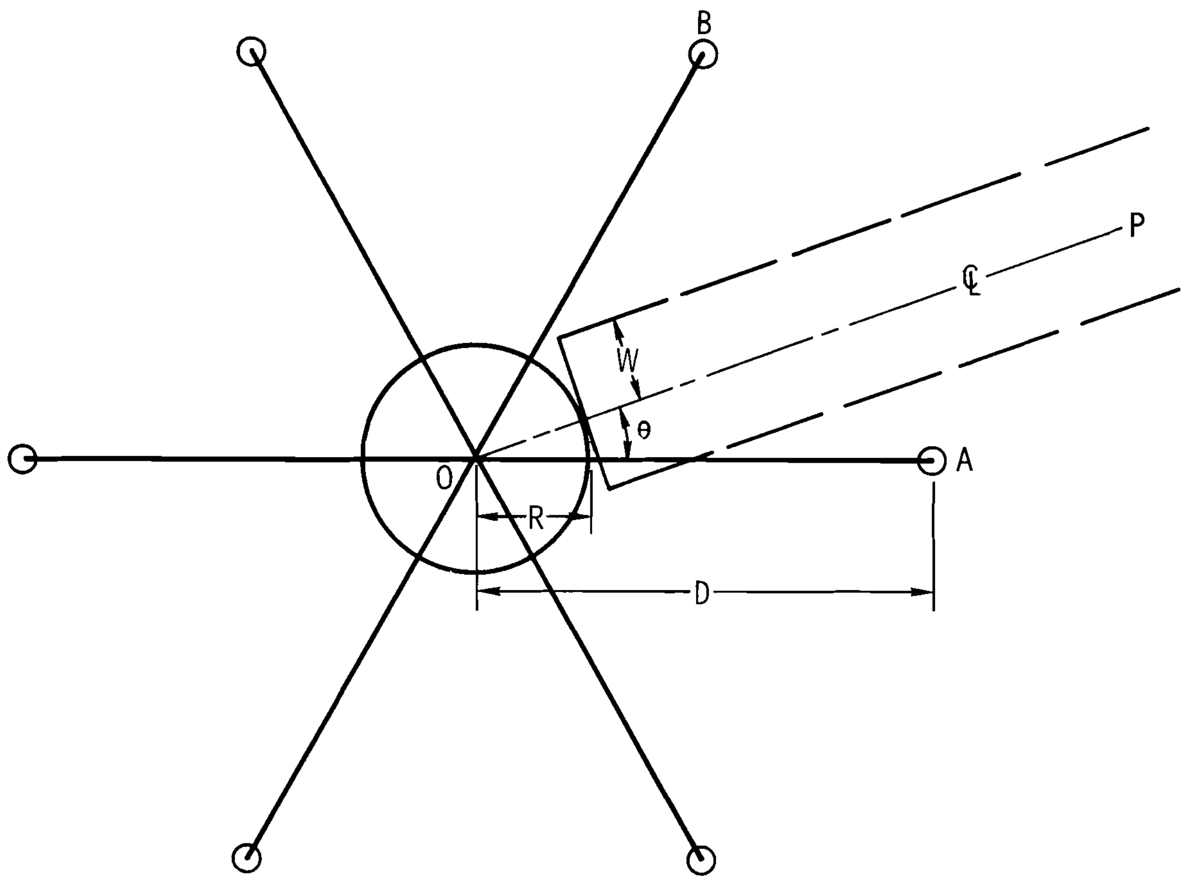
Ambient Radiation Monitor	Detection Levels	
	Gamma (R/hr)	Beta (Rad/hr)
Containment Vessel	1 to 10^{6}	10 to 10^{6}
Reactor Building	10^{-2} to 10^{4}	10^{-2} to 10^{4}
Environs	10^{-2} to 10^{4}	10^{-2} to 10^{4}

if the average energy is known. King[38] used twelve ion chambers positioned equidistantly around a circle with radius of 1000 feet in addition to an air sampling array. Both King and Henderson indicated this technique was useful for order of magnitude estimates.[37,38] Palmer[39] suggested the use of three detectors approximately 100 meters apart and approximately 150 meters from the reactor building to detect the passage of a cloud of radioactive gas resulting from an accidental release. The accumulated dose rate from the three detectors was calculated to be independent of the direction the cloud takes as long as the cloud is in the region between the two extreme detectors or just outside one of the detectors. King[38A] has also described a "Skyscanner", useful for determining the vertical radioactivity profile within a cloud, and which, if two or more are used, can accurately locate cloud position. The Skyscanner, designed for detecting releases of radioactive material from underground nuclear explosives, consists of a sodium iodide detector mounted in a tracking pedestal with both horizontal and vertical control and readout. This might be suitable for emergency cloud monitoring with modifications for scatter, changes in photon spectrum, and distance.

An alternative method, similar to those of Henderson[37] and King[38,38A] has been described by Watson and Strenge.[40] This method may offer increased accuracy along with simplicity and could be combined with the Skyscanner. A knowledge of the wind velocity, i.e., wind vector, and flux at two fixed points is required. A minimum of six detectors should be placed in a circular array at 60° intervals to provide sufficient redundancy. The release rate estimate can be made from measurements at any two of the three detectors within ±90° of the horizontal plume direction (θ). At a multireactor site, the six detectors may serve more than one reactor as long as the distance between the reactor and the detector is less than 500 feet.

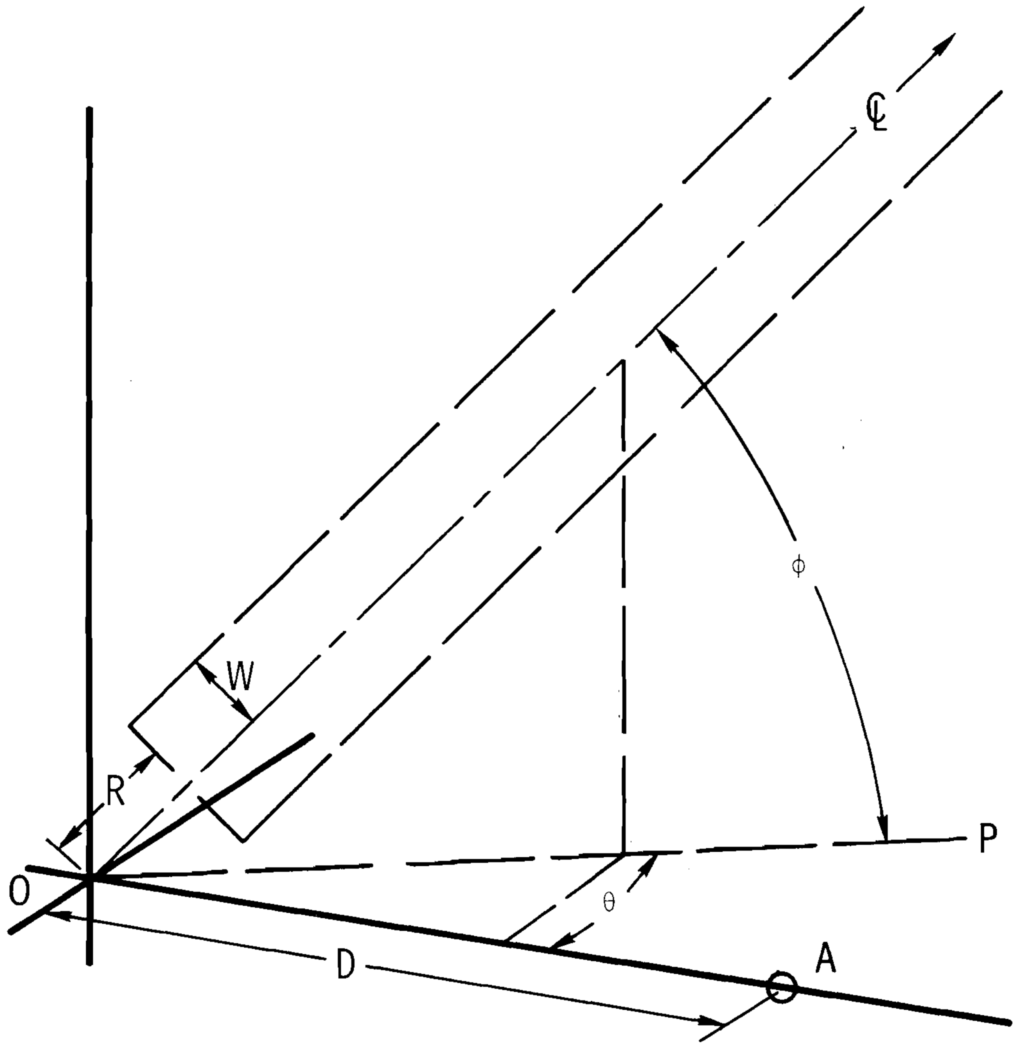
Geometric relationships are shown in Figure 6. The path of the plume is determined by the wind direction as shown in Figure 6. Radioactive material is assumed to be uniformly distributed in the plume. The plume is assumed to be a right cylinder of radius W whose centerline and the line from the point of release to the nearest detector subtend angle θ. Thus, θ is the horizontal angle between the direction of the plume travel and the bearing of the nearest detector, and with 60° spacing between detectors, cannot exceed 60° with one detector out of operation.

Under some conditions the plume from the reactor building may rise as it travels downwind, making an angle ϕ with the horizon, as shown in Figure 7. For a specified direction of travel, the photon flux at the detector descreases with increasing values of ϕ.



○ = DETECTOR
$\overline{OP}$ = CLOUD CENTER LINE
R = SOURCE RADIUS
D = DISTANCE TO DETECTOR
W = RADIUS OF PLUME
θ = ANGLE OF PLUME CENTERLINE WITH DETECTOR DIRECTION

FIGURE 6. Source-Detector Geometry in Horizontal Plane



R = SOURCE RADIUS

D = DISTANCE TO DETECTOR

W = RADIUS OF PLUME

θ = ANGLE OF PLUME CENTERLINE WITH DETECTOR DIRECTION

ϕ = VERTICAL ANGLE OF PLUME CENTERLINE WITH HORIZONTAL PLANE

FIGURE 7. Three-Dimensional Source-Detector Geometry

An estimate of the release rate can be obtained by measuring photon flux at the detectors on either side of the plume (i.e., the two detectors nearest the plume) and obtaining the ratio of flux at the near detector to that at the other detector. The measured wind direction determines the angle θ, and hence the plume centerline. By plotting θ and the flux ratio on Figure 8, an effective plume rise angle ϕ can be determined where the angle between detectors is $<60°$. Figure 9 should be used if the angle between detectors is $>60°$ and $<120°$. With these data, a quantitative estimate of flux at the detector equivalent to 1 Ci/m of plume length can be obtained from Figure 10. Figures 8, 9 and 10 assume the detector is located 100 meters from the reactor.

The conversion from photon emission rate to Ci of noble gases released per second depends on the operating history of the reactor. Figure 11 is a plot of conversion factors, as a function of operating time and decay time after shutdown. The conversion factor gives curies of noble gases per photon/sec produced (of energy >2 MeV) from noble gases plus daughters.

IV.A.2. Source Detector Distance

Another important consideration is distance of the detector from the reactor or source of the leak. The distance must be sufficiently great to obviate local aerodynamic and thermal effects on the plume, and thereby obtain reasonably accurate estimates of vertical and horizontal angles, ϕ and θ. The distance, however, cannot be too great or the sensitivity will be reduced. For purposes of this study a distance of 100 meters has been selected.

IV.A.2. Plume Detector

It was shown previously that the noble gases, and in particular, the radiokryptons and daughters produce most of the photons with energies ≥2 MeV. Thus a measurement of photon energies ≥2 MeV appears to be well-suited to quantify the release. A NaI(Tl) crystal appears to best fulfill the need for sensitivity, ruggedness, and convenience of operation to quantify photons of these energies. In addition, NaI(Tl) detectors are

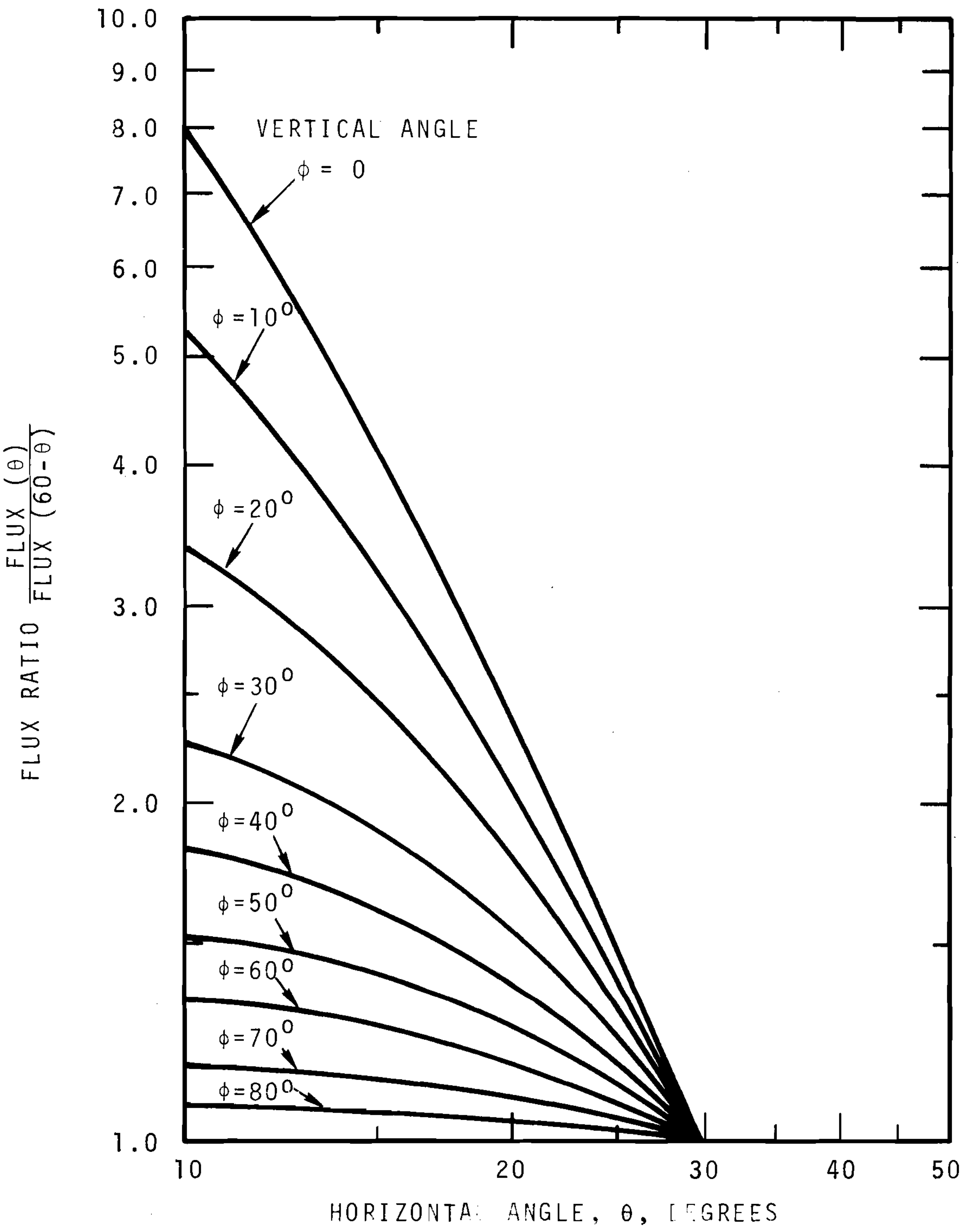


FIGURE 8. High Energy Photon Flux Ratio as a Function of Plume Direction for Detectors Separated by 60°

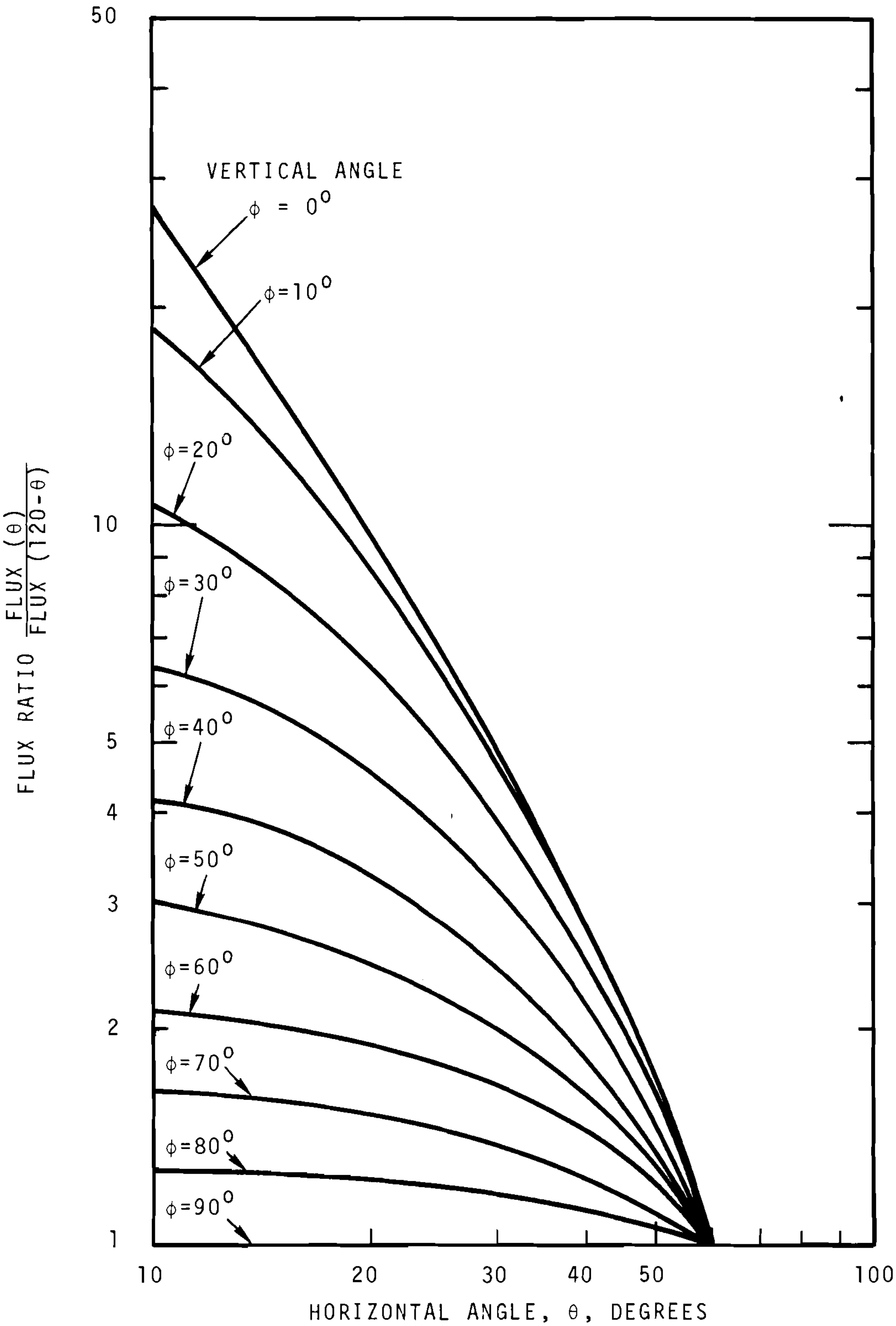


FIGURE 9. High Energy Photon Flux Ratio as a Function of Plume Direction for Detectors Separated by 120°

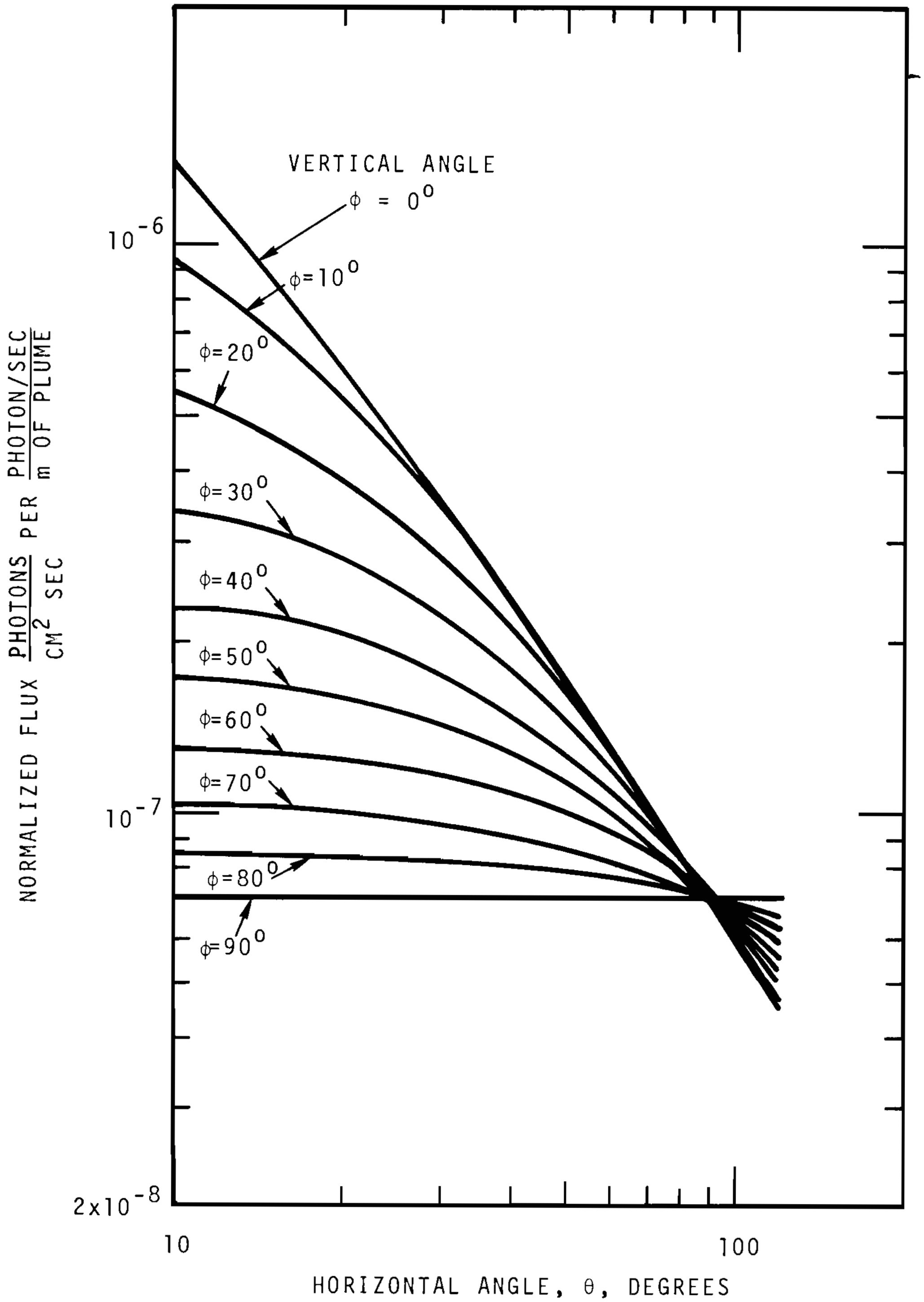


FIGURE 10. Normalized High Energy Photon Flux as a Function of θ and ϕ

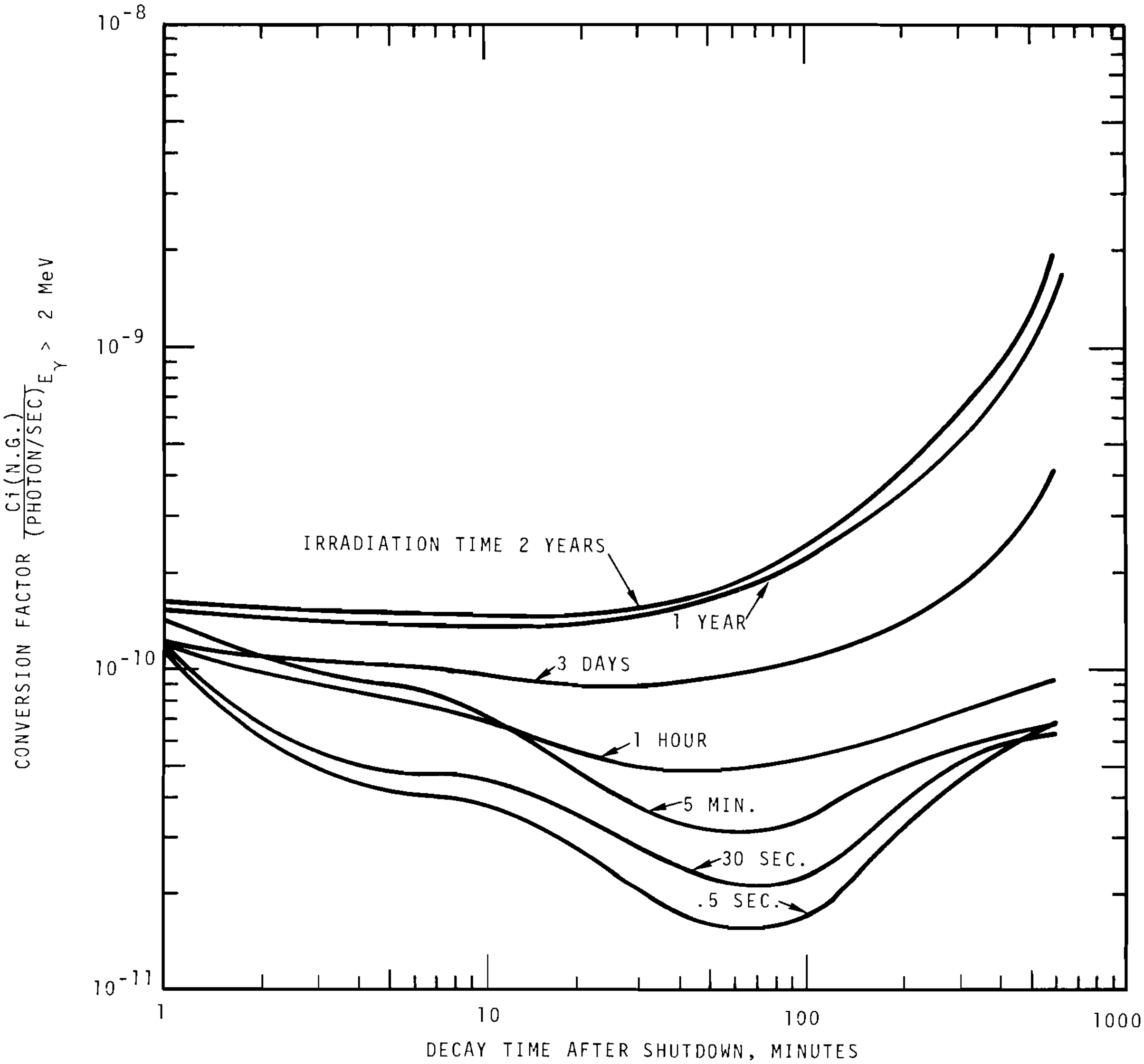


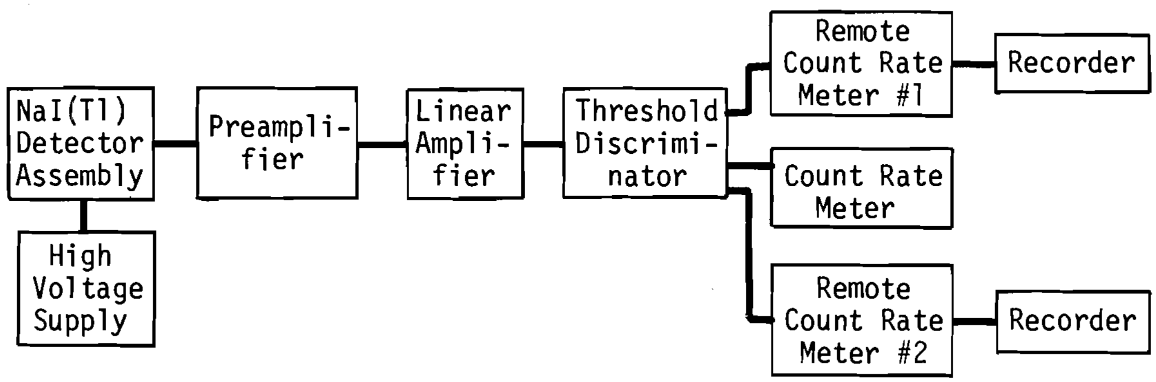
FIGURE 11. High Energy Photon Emmission Rate from Noble Gases as a Function of Fuel Irradiation Time

relatively inexpensive and their technology and characteristics are well-known. At some future time, semiconductor detectors may provide improved detection capability, but at present these detectors are too small to provide adequate sensitivity, and in addition are delicate, expensive and may require cryogenic operation or other special care.

Detection of photon energies ≥2 MeV provides certain advantages, particularly with respect to sensitivity. The natural background radiation in this region is small--generally not more than a few counts per minute. Hence, a 3 in. x 3 in. crystal could be used in conjunction with a threshold discriminator or a single channel analyzer to detect plume concentrations on the order of 1 mCi/m of cloud length or release rates as low as a few millicuries per second. A possible interference might be from direct radiation from the bulk of the inventory, which essentially all remains in the containment vessel. To eliminate this difficulty, a shadow shield equivalent to 10 inches of lead should reduce the contribution from this source by a factor of 10^5 and this should be adequate. Another method might be to place the detector in a small trench which would provide adequate shielding from direct radiation from the containment vessel. Skyshine interference should be negligible, since there are relatively few photons with energies above 2.65 MeV, and most scattered radiation would therefore result in photons with energies less than 2 MeV. The optimal solid angle for minimal skyshine and good detection of the plume should be on the order of a steradian.

A cylindrical detector, at least 3 inches in diameter should provide, as a minimum, an efficiency of at least 25% for a point source in contact with the crystal. The resolution should be ≤10% FWHM at 2.5 MeV to minimize contribution from photons with energies below 2 MeV. The crystal itself should be directly mounted to the photomultiplier face, and the complete assembly hermetically sealed in a light-tight magnetic shield housing. The thickness of the material over the detector should be no more than 750 mg/cm^2. Integral crystal-photomultiplier tube housings are considered best for the emergency detection situation since the detectors may be required to function under rather severe conditions. In addition, low noise connectors and photomultiplier tubes are recommended and the photomultiplier should be provided with a mu metal or other suitable magnetic rf shield.

The detection scheme described above implies six individual systems, with a central readout. While it is possible to have only the detectors and preamplifiers remote, it appears that a superior system would be achieved with present capabilities by providing six essentially self-contained systems and telemetering or otherwise transmitting the output signal to a central data collection point which may be the control room. Shown below in block diagram is one of the six basic detection and readout systems.



The sensitivity of the entire system should be adequate to detect 20 cpm above normal background for photons with energies $\geq$2 MeV within five seconds at the 95% confidence level. The detection range should be over at least five orders of magnitude covering plume concentrations from 0.01 to 10^3 curies per meter of cloud length.

Accurate calibration of the radiological measurement system is vital to the interpretation of the data collected. Direct calibration of the system using a source which emits photons in the appropriate energy range provides a complete system check. There are, unfortunately, no conveniently available long-lived sources that emit photons in the 2 MeV region. However, the photon cascade associated with ^{60}Co decay provides a 2.5 MeV coincidence approximately 1% of the time, and this nuclide, with a 5.26 year half-life, would make a suitable calibration source.

IV.B. METEOROLOGICAL MEASUREMENTS

Performance Criteria for Meteorological Instruments are presented in Section VI.B.

Whether conducting a postaccident evaluation or determining action to be taken during an accident, it is necessary to have on-site meteorological data from which accurate plume diffusion and transport estimates can be made. The data required and the data acquisition system necessary to provide the information on the direction and dispersion of a radioactive cloud, or for performing postaccident analyses are discussed in the following sections.

IV.B.1. Meteorological Data Requirements

Basically two types of information are necessary: the turbulence or diffusive capacity of the atmosphere, and the transport or path of flow of the air mass containing the plume and the eddies effecting its diffusion.

Knowledge of atmospheric diffusion processes is essential to predicting the extent and concentration of a radioactive release, and to estimating deposition. In Table 5, common atmospheric diffusion models are given for both continuous and semi-instantaneous sources along with data and instrumentation requirements for each. These are listed to demonstrate the range of input parameters common to most diffusion models and are not intended to indicate a preference for these models over others which might not be listed. A more complete discussion of the various models can be found in the references cited and in Slade.[41]

There is obviously a broad range in the required instrument types, from visual observation to a radar tracking system, with variations in the applicability and reliability of these different techniques as well. As no one model is superior in all situations, the criteria specified in Section VI.B. will not be based on any particular model. Basically, only four parameters are required: temperature (T), wind speed ($\bar{u}$), standard deviation of the lateral angular component of the wind vector (σ_θ), and standard deviation of the vertical angular component of the wind vector, (σ_ϕ). Direct measurement of the turbulence indices σ_θ and σ_ϕ, the standard deviations of

TABLE 5. Examples of Atmospheric Diffusion Models

Technique	Required Data	Required Instrument	References
	Continuous Sources (Plumes)		
Hay-Pasquil (1959)	σ_θ, σ_ϕ, $\bar{u}$	Fast response bivane anemometer	42
Sutton's Model	$\frac{\partial T}{\partial z}$, $\bar{u}$	Vertical array of differential temperature sensors and anemometers	41,43
Pasquil's Curves (1958)	$\bar{u}$, solar radiation, % cloud cover	Visual estimates or measurements by observes	44
(1970)	$\frac{\partial T}{\partial z}$ $\frac{\partial \bar{u}}{\partial z}$	Vertical array of differential temperature sensors and anemometers	45
Hanford Model	σ_θ, $\bar{u}$ $\frac{\partial T}{\partial z}$	Vertical array of differential temperature sensors and fast response vane anemometer	
Tracking Neutrally Buoyant Ballons	Balloon position, Time	Tracking radar, airborne radar transponder, tetroons	41
	Semi-Instantaneous Sources (Puffs)		
Smith-Hay (1961)	σ_θ, σ_ϕ, $\bar{u}$	Fast response bivane anemometer	46
Cramer (1964)	σ_θ, $\bar{u}$	Fast response vane anemometer	47
Tracking Neutrally Buoyant Balloons	Balloon position, Time	Tracking radar, airborne radar transponder, tetroons	47

σ_θ = standard deviation of lateral angular component of wind vector

σ_ϕ = standard deviation of vertical angular component of wind vector

$\frac{\partial T}{\partial z}$ = vertical temperature gradient

$\bar{u}$ = mean wind speed

the lateral and vertical angular wind direction fluctuations, would provide better estimates of dispersion than measurement of related parameters such as thermal stability. The latter technique has predominated; however, as instrumentation for measuring σ_ϕ and σ_θ has improved, models dependent upon direct measurements have evolved. As these models are improved, turbulence measurements should become more common as input parameters for diffusion and deposition estimates. These models should improve the accuracy of predictions and may be preferred in the near future. It is notable that Pasquill, a universally recognized worker in the field, has stated that direct eddy measurements are to be preferred.[45]

A basic limitation in diffusion models currently being applied is that they employ data obtained only at the source for predicting diffusion downwind. The reliability of diffusion estimates decreases with distance from the source since the turbulent conditions at downwind locations may differ from those at the source.

An analogous problem occurs when trying to predict air parcel trajectories. When only the wind parameters at the effluent source point are used, large errors in transport estimates for distances of more than a few miles (or a few hours) occur due to the parcel being caught up in local mesocale flow patterns caused by local terrain features.[48] Mesoscale circulations can cause surprisingly complicated and variable trajectories in many cases. Consequently for situations where the effects of an accident could be significant out to a distance of several miles, wind direction and speed measurements may be required at several locations in the area. The necessity of such additional measurements will have to be determined on a site-by-site basis and will depend upon complexity of local flow features and plant parameters. Wind speed and direction information is frequently available from airports, local and federal agencies, and military installations and these sources might be made a part of an emergency system, although additional measurement systems will likely be required at most sites.

In most situations, transport is independent of diffusion. However, in thermally stable situations, the mean horizontal wind direction changes significantly with relatively small changes in height. Although vertical diffusion is inhibited in stable situations, it is sufficient to cause material at the top and bottom of the plume to be transported in different directions causing the plume to be fanned out horizontally. The point is that the vertical diffusion data in this situation are a requirement for accurate transport estimates. The occurrence of this situation, of course, will vary from site to site.

The fanning process caused by the wind direction shear can also enhance the diffusion. Two other processes which can have a major effect on the air concentrations in the plume at ground level are plume rise and deposition. Plume rise, which occurs as the result of buoyancy and momentum, determines the effective source height in diffusion models and generally is modeled in terms of the meteorological parameters of wind speed and thermal stability ($\Delta T/\Delta Z$) and the source parameters of efflux velocity and temperature and the orifice size. Consideration of the inclusion of the effects of plume rise in determining emergency action seems unwarranted because of the uncertainties in the source parameters at the time of the accident, except possibly in the case of accidental stack releases, and since conservative estimates can be made assuming a constant source height. In postaccident analyses, inclusion of plume rise effects could be reasonably accomplished and may be of value in the postaccident evaluation. Plume rise resulting from accidents could be of the order of a few hundred meters and hence could have a significant effect upon concentration and deposition estimates. The point to note here is that the meteorological data required is not in addition to that already defined as necessary for diffusion models.

The deposition on, or attachment to, surfaces of the materials in the plume can result in a significant redistribution of the released material from that which could obtain without consideration of deposition. Dry deposition of airborne gases and particles can be included in diffusion models by employing empirically based deposition "velocities" which vary with material and surface type, and thermal stability. The incorporation of the effects of dry deposition in a diffusion model does not require measurements beyond those already identified. It should be noted, however, that some diffusion results include the effects of dry deposition to varying degrees.

A second form of plume depletion is wet deposition or washout by rain or snow. When washout occurs, it is reported that it can result in deposition which is roughly an order of magnitude greater than that due to dry deposition.[49] It is unlikely that the effects of washout can be accounted for in any quantitative way during an accident, but an awareness of the significance of the process could be of importance. In a post-accident analysis a quantitative assessment would be possible and could be of value in determining and describing the effects. Quantitative estimates of washout will require the incorporation of an appropriate precipitation rate measurement method into the measurements system. The method might be an automatic device or visual observations.

IV.B.2. Measurement of Diffusion Parameters

Table 5 suggests that a single "profile tower" instrumented to measure σ_θ, σ_ϕ, T and $\bar{u}$ at multiple elevations will provide the data necessary for most models. In each of the models, the required data have been correlated to the standard deviation of plume spread, σ_y and σ_z, which are the independent variables in applied diffusion models. Since it is the turbulent eddies of the atmosphere that diffuse airborne material, it is more direct to correlate σ_y and σ_z to measured wind fluctuations than to secondary parameters such as stability; it has been demonstrated empirically that the correlations are high.[41,42,46,50-52]

A system employing instrumentation commensurate with the state-of-the-art should include direct eddy measurements. This, added to the required temperature gradient measurements enhances the overall system reliability. Thus an independent sensor system is available in the event of questionable results or a failure in the eddy measurement sensors which may be somewhat less reliable. The measurement of $\bar{u}$ is required by all applied continuous and puff source models. It is noted, however, that the basic requirement is to determine, either directly or indirectly, the lateral and vertical dispersion. In the past both have been parameterized in terms of either σ_θ, ΔT, or the Richardson number, Ri (defined on next page). However, σ_θ is very poorly correlated with either σ_ϕ, ΔT, or Ri, therefore, it is considered necessary to measure σ_θ directly to determine σ_y. The correlations between the parameters σ_z, σ_ϕ, ΔT, and Ri are all quite good, however, and although it is most desirable to directly measure σ_ϕ, it can be estimated by employing established correlations to Ri.

It is considered that measurements to at least the maximum height at which material could potentially be released is a minimum requirement. Maximum stack heights may exceed what could be considered economical tower heights. In this situation an acceptable approach would be to use tower data to a maximum practical level, and data from stack-mounted instruments at higher levels. The stack data could then be corrected for excessive stack influences. Measurements could reasonably include wind speed and direction and possibly temperature. Nomograms to correct for the stack's influence, if based on *in situ* measurements and studies reported in literature, may be sufficiently effective to make the data meaningful.

It is recommended that the minimum profile tower height be 60 meters irrespective of the maximum potential release point height. It should be recognized, however, that predictive capability will generally be limited by tower height. For example with greater tower height it is possible to increasingly take account of such factors as fumigation conditions, plume rise, and plume shearing.

A tower which meets the minimum height requirement should be instrumented as a minimum at three levels, namely 2, 9 to 15, and 60 meters above the surface. (This assumes the surface in the vicinity of the tower, within say 60 meters, is relatively free from significant terrain variations or dense high vegetation. If such roughness elements do surround the tower, the measurement heights given should be made from the average height of the roughness elements.)

For facilities with potential release points exceeding 60 meters, the uppermost instrumented level should be placed at the level of the highest potential release point. Each level should be instrumented to measure wind direction and direction variability (σ_θ), speed, and temperature. At a multifacility reactor site, one tower will be adequate if the distance from reactor to tower is no greater than two to four miles. This distance may be less depending on individual site characteristics.

As mentioned above, the vertical gradients of wind speed and temperature can be used to estimate σ_z, however, these parameters must be measured very accurately. For example, Table 6[45] demonstrates the relationship between stability classes and the Richardson number, Ri, which is a measure of the tendency for turbulence (negative for large turbulence).

TABLE 6. Relationship Between Stability Classes and the Richardson Number

$$Ri = \frac{g}{T_0} \frac{\frac{\partial \theta}{\partial z}}{\left(\frac{\partial u}{\partial z}\right)^2} \quad \text{, where } \frac{\partial \theta}{\partial z} = \frac{\partial T}{\partial z} + \frac{0.98°C}{100 \text{ meter}}$$

	Stability Class	Ri @ 2 m
A	Extremely unstable	-1.0 to -0.7
B	Moderately unstable	-0.5 to -0.4
C	Slightly unstable	-0.17 to -0.13
D	Neutral	0
E	Slightly stable	0.03 to 0.05
F	Moderately stable	0.05 to 0.11

Inspection of Table 6 indicates that Ri changes as little as ∿0.04 between the neutral and stable classes. As a minimum then it would be desirable to distinquish Ri to ± 0.02. For Ri at 4 meters, (the approximate geometric mean of 2 and 9 meters), this would be ∿ ± 0.04. Calculations using sample data of $\Delta\theta$ and Δu for determining Ri at 4 m indicate that a change of only 0.04°C will cause a 0.04 change in Ri. Similarly a change of 0.05 m/s will cause a 0.04 change in Ri. In a situation where both factors were contributing in such a way as to cause the maximum error, $\Delta\theta$ and Δu would need to be measured to about ±0.02°C and ±0.025 m/s for Ri to be ∿ ±0.04.

These accuracy requirements are excessive not only for routine instrument systems but also for experimental systems. Reasonable goals for routine systems would be Δu to $\sim \pm$ 0.2 m/s and $\Delta\theta$ to $\sim \pm$ 0.05°C. An approximate analysis using these ranges indicates that in the worse case it may only be possible to distinguish between broad, neutral, stable, and unstable classes. Since the change in $\chi_p\bar{u}/Q$, the normalized centerline concentration, from Pasquill Classes A to F spans approximately two orders of magnitude at a few hundred meters downwind and three orders at 10 kilometers, it is apparant that these must be considered minimum requirements if the Richardson number is to be of value for determining σ_z. For these reasons, the direct measurement of either σ_ϕ or σ_w (standard deviation of the vertical component of the wind vector) with a bivane or propellor, respectively, is strongly recommended as an optional method of obtaining σ_z at the 9-15 and 60 meter levels. (At present measurements of σ_ϕ or σ_w at 2 meters are not considered necessary.) However, devices for direct measurement of σ_ϕ or σ_w are of relatively light weight construction and would not have the environmental survivability of the sensors required for determining Ri. Therefore, direct measurements of σ_ϕ or σ_w must be considered highly desirable, but as a complementary option to devices for determining Ri through which the vertical dispersion can be indirectly inferred. The accuracy requirements considered consistent with available models, instrumentation, and the present application are ±20% for σ_θ and ±35% for σ_ϕ or σ_w.

IV.B.3. Transport Estimation

At many sites a continuously operating network of towers instrumented to measure windspeed and direction will be necessary to determine the trajectory or position of a plume as a function of time. This necessity arises because of the fact that measurements of wind direction and speed at a single point are frequently only applicable for a few miles. As mentioned previously, the requirement for a system of transport towers will be determined by the topography of the site and plant parameters. With present reactor power levels it is anticipated that plume trajectories may need to be determined to distances on the order of 10 miles. Because of the variability of plant parameters and topographies, the required number and placement of transport towers should be evaluated to determine the compatibility of the system with the emergency action plan and anticipated postaccident analyses requirements at the site. Although experience in the analysis of mesoscale wind flow patterns can guide tower placement, some adjustment may be necessarily based upon experimental investigations and the comparison of predicted and observed trajectories.

Experience with the mesoscale transport of diffusion plumes indicates that the instruments should be placed at approximately 15 to 30 meters above the local roughness elements or vegetation canopy. In forested locations the region above and below the canopy represent two markedly different transport regimes and it may be necessary to place a second level of wind speed sensors below the canopy.

Open triangular frame towers and small diameter masts, are practical means of supporting instrumentation for extended periods. Their use has resulted in data to demonstrate the extent of tower influence upon wind measurements. It is reasonable to expect that other apparently suitable structures may be in place such as buildings, trees, power line supports, and stacks. Since the effect of such structures upon wind measurements can be significant, due consideration must be given to them. Mountings on buildings or towers or masts very near buildings should be considered inadequate. Towers or masts are preferable to stacks, but the economy of utilizing facility stacks must be considered when stack heights make the costs of an independent tower unreasonable.

Accuracy requirements for average wind speed and direction commensurate with available instrumentation and the application of the measurements are considered to be ±0.5 mph or 5%, and ±5 degrees with a starting threshold of <2 mph for measurements of both speed and direction.

IV.B.4. Data Recording, Processing and Display Requirements

Specific recommendations for equipment to record, process, and display data will depend upon the model(s) used and the requirements of the emergency plan. The obvious general requirements should include, immediate access to summarized data for real-time or postaccident evaluation; that the errors introduced by recording, processing, and display equipment either be included in the data accuracy limits identified or that they be very small in comparison to the acceptable errors; and that all data be recorded such that a permanent record will be assured. Display of transport tower wind speed and direction data at the emergency control center location will require real-time data transmission by an appropriate technique such as telemetry or telephone line. In processing and displaying data in a timely manner, consideration should be given to automatic data handling by analog and/or digital computers.

Automatic real-time techniques for calculating the standard deviation of fluctuating meteorological variables have been available since the application was suggested and demonstrated by Jones and Pasquill in 1959.[53]

A similar approach centered around the use of an analog computer, was suggested by Brock and Provine.[54] Gill and Bierly[55] described a system of the Brock/Provine design installed at the Enrico Fermi Atomic Power Plant for controlling the release of radioactive gaseous wastes from a 60 meter stack. The Brock/Provine design will permit calculating standard deviations for periods of up to one hour with less than 5% error as designed. It was suggested that closer component tolerances could improve the accuracy. At some sites, existing computer facilities may be available to perform these data processing functions. If such a capability is available, the feasibility of programming accident response decisions and certain aspects of trajectory analysis should be considered. From the standpoint of response time and accuracy, as much automation as possible is desirable; but it will have to be considered only as a tool for, and not a replacement for, emergency personnel capable of using basic data to arrive at meteorological conclusions.

IV.B.5. Location of Profile Tower, Transport Tower(s), and Tower Instrumentation

The basic purpose of the near-source meteorological profile tower is to measure the parameters from which diffusion and transport outside of the area controlled by the facility can be predicted. This requires that the instruments be located where conditions are representative of conditions downwind as opposed to those within the controlled area, as the latter has a special microenvironment set up by superimposed building wakes and heat plumes.

These considerations will likely require that the tower be located away from the facility complex in most cases. This assumes that the facility is an anomalous terrain feature. In populated areas where the facility is surrounded by other buildings, the goal is to place the tower at a position that will reflect the general character of the area rather than in some special microenvironment. Actual profile measurements of the parameters of interest can help significantly in detecting data distortions. Placement of the profile tower away from the facility is also considered desirable from the standpoint that the extreme winds associated with tornadoes and waterspouts are very local and less likely to effect both the facility and the towers if they are separated. Another consideration in placing a profile tower relative to an obstruction is the wind direction climatology. If the climatology shows a particular wind direction with a very low percentage of occurrence, the tower can be placed in the corresponding downwind sector and not be in the obstruction's influence but a small percentage of the time. Of course, if winds from that direction correlate significantly with nonrepresentative atmospheric diffusion conditions, the tower must be located further away from the obstruction or at a different azimuth location.

Similar considerations must also be given to natural terrain features such as vegetation, hills, bluffs, valleys, slopes, water bodies, etc. Where these features control the diffusion climatology over the region of which the tower data are to be representative, it is their influence on diffusion that is to be measured. However, where these features are only anomalies in the region, their effects should be avoided.

Similarly, it is not important that transport towers be located in a region that is representative in terms of roughness of diffusive capacity, but the flow at these sites must be representative of as large an area as possible. Obviously, judgments on these matters will have to be made for each individual site by meteorologists experienced in mesoscale flow. It should be recognized that in some cases experimental studies may be required to determine the need for and placement of transport towers.

Various investigators have observed that towers and stacks have significant effects on meteorological instruments supported on horizontal booms. The conclusions of Gill, et al.[56] are representative and are as follows:

For Open Triangular Towers with instrument booms parallel to tower sides:

1. One sensor set at two diameters away from the edge of the tower will provide wind speed ±10% and wind direction ±5° to ±10° for an arc of 330°.
2. If accuracy to ±5% for speed and ±5° for direction is desired over 360° of azimuths, two instrument sets 180° of arc apart at a distance of not less than 1.5 diameters are recommended.

It is desirable to minimize tower induced error as much as possible; however, adequate support of long instrument booms may become difficult beyond 2-3 diameters beyond the edge of a tower. Therefore, with one instrument set an instrument boom two tower diameters in length is considered the minimum requirement. Longer booms are desirable if their integrity can be assured. Errors can be reduced by placing the instruments on the predominate windward side of the tower; however, placement should also consider other factors such as the distribution of stability with wind direction and the distribution of population about the site. Little data appear to be available concerning the effects of towers on measurements of σ_θ and σ_ϕ or σ_w, but that which does exist indicates that large errors can occur. During periods when the instruments are significantly in the wake of the tower, diffusion estimates should be primarily based upon thermal stability or Richardson number estimates. A desirable complementary option would be to place a duplicate set of wind instruments at the 9-15 meter level on the opposite side of the tower.

The effects of cylindrical stacks on measurements of wind speed and direction are summarized below for reference.

1. At a distance of 3 diameters, one instrument set will measure wind speed to ±10% for a 180° arc and wind direction to ±5% for a 300° arc.
2. At a distance of two diameters, two instruments set 180° apart will provide wind speed to ±10% and direction to ±5% over 360°.
3. The accuracy of top level instruments can be greatly improved by locating them 0.5 diameter or greater above the stack.

IV.B.6. System Calibration and Maintenance

Calibration and maintenance requirements are dictated by the accuracy and reliability requirements for the data. Guidance as to the frequency and procedures for the calibration and maintenance of meteorological sensors and peripheral equipment is best obtained from the manufacturers. Actual use of manufacturer's recommendations will quickly reveal whether the procedure and frequency are adequate for a specific system and environment. All calibration equipment should be traceable to appropriate standards. Calibrations should include system end-to-end checks for the range of probable environmental conditions. As a minimum requirement, the entire meteorological system should be checked at least quarterly and calibrated and maintained as necessary.

IV.B.7. Sensor Environmental Operating Conditions

It is recommended that sensor system operating conditions be prescribed on a site-by-site or regional basis to avoid imposing unreasonable requirements on facilities not experiencing extremes. The recommended guideline is that the sensor system should be designed to meet the specified data and data accuracy criteria for the range of climatological conditions at a particular site and that there should be an extremely small probability that a measurement of wind speed, direction, and direction variability would not be available in the event of an accident at least one level. In regions frequented by hurricanes and/or tornadoes such an assurance could be provided by establishing a mast and wind instrument set of rugged design at a point separated from both the facility and the profile tower. Instruments of rugged design are available which can withstand hurricane force winds and the redundancy and separation of a rugged wind set system make the probability of a tornado striking the facility, the profile tower, and the rugged wind instrument set highly improbable.

The wind sets for transport towers should be capable of operation under climatological ranges for the specific site.

It should be recognized that for climatological extremes at some sites, it may be impractical to meet certain of the criteria established and that individual site evaluations and judgments will be required.

IV.C. MEASUREMENT OF GASEOUS EFFLUENT

Monitoring within the containment vessel a ventilation system or a stack, can be categorized as direct or indirect. In the case of direct monitoring, the effluent is examined without removal from the system or without intervening treatment of any kind. Thus, direct monitoring is a rapid method that in general requires only relatively simple instrumentation.

However, direct monitoring does not usually provide information on the chemical and physical form of the release or of the isotopic composition. For these reasons, direct monitoring systems are usually not adequate for characterizing an accidental release. However, in some applications, direct monitoring may be advantageous.

Indirect monitoring requires treatment or removal of the effluent or a sample from a system. The point from which a sample is withdrawn must be chosen with careful attention to factors which may make the sample unrepresentative. The degree of freedom in choice of sampling location may be very restrictive or quite nominal depending upon the nature of the process, the integrity of the air cleaning system, the physical and chemical form of the effluent, and the basic aerosol physics dictating the geometrical relationships for representative sampling.

IV.C.1. Characteristics of Gaseous Effluent

The stack release will include fission products and their daughters as well as activation products in a variety of chemical and physical forms. Although a large fraction of the radioactivity probably will be from the noble gases, consideration must be given to other gases as well. Tritium, produced both by activation and fission, can occur as nascent or molecular hydrogen, in water, or in particles which contain hydrated salts.

Important gaseous compounds of radioactive heavy metals and other elements may be formed in special circumstances. If compounds of this kind are anticipated, great care must be exercised in sampling and monitoring to assure that materials of the sampling lines are chemically nonreactive and that temperatures are sufficiently high to preclude condensation.

As distinct from the permanent gases, vapors are those elements or compounds which at ordinary temperatures in the condensed phase have appreciably high vapor pressures. Common nuclides in this category are radioiodines, which sublime readily from the solid at room temperature, even though the melting point is 113.5°C. Elemental iodine and most iodine compounds are chemically reactive, as well, and materials used in the sampling system must be chosen to avoid interference from this source.

Aerosols consist of liquids or solids in a fine state of subdivision, and for practical purposes can be considered to have aerodynamic mass median (AMM) diameters smaller than 50 micrometers. Particles can consist entirely of the radioactive element or its compound, but more often are nonradioactive material contaminated with radioactive material. In most situations involving airborne radioactive material from a reactor accident, the pure radioactive material represents a small fraction of the total solids content. Particle size and solubility are of great importance in determining the biological significance of particles when breathed, yet particle size information is seldom gathered in routine operation or during accidents in which radioactive material is made airborne.

IV.C.2. Stack Effluent Monitoring

Performance criteria for the Stack Effluent Monitoring System are presented in Section VI.A.3.d.

IV.C.2.a. Direct Monitoring

Direct measurement methods are used in many instances for routine monitoring of gaseous effluents in the stack. However, the use of this technique is considered to be impractical for emergency purposes due to the high level of radiation that would be present and the unknown character of the effluent. Thus, no direct monitoring method is suggested. .

IV.C.2.b. Indirect Monitoring

Effluent samples must represent the true composition and concentration of the radioactive material being released to the environment over some selected time interval. It follows that the sample point should be at or near the point of release to the environment. For installations which discharge all ventilation air through a single tall stack, air from the top of the stack should be sampled. Since some stacks are over 200 feet tall and compromises may be faced in transporting the sample to the surface station, the question immediately arises as to whether the sample must be taken at the very top of the stack or whether it can be removed at a point somewhere below the top. This dilemma cannot be answered with a simple statement that the sample must be taken from the top of the stack, although this location is preferred. A point other than the actual discharge point can be chosen if there are no design features or physicochemical reactions which will render the sample nonrepresentative.

When sampling for radioactive gases, the essential criterion is that the sampling point should be selected far enough downstream from the injection point that the injected gas will be thoroughly mixed with the carrier gas. This distance will vary depending upon the conditions of turbulence, distance from the wall at which injection occurs, and the size and orientation of the injected gas port into the main stream. Generally, ten duct diameters downstream from the injection point in a turbulent stream is sufficient to uniformly mix the gas. In most ventilation systems the entrance of the contaminated gas occurs at many points far upstream of the discharge point to the atmosphere. Passage of the gas through the air cleaning system and the exhaust fans further assure uniform mixing prior to the point of sampling. In the event that uniform mixing at the selected point of sampling cannot be assured, multiple inlets in the sampling probe can be used to extract samples from several points within the stack. Empirical verification that the sampling point and method do provide a representative sample is highly desirable, and can be done by sampling a known concentration of a tracer gas injected at the normal entrance point of the gas into the main exhaust system.

Design of a representative particle sampling system requires either a knowledge of the particle sizes to be sampled, or an assumption that all sizes of particles will be present. The latter assumption is required when the source of the particles is unknown, as with accidental releases. When particles are to be sampled from a tall stack the same considerations regarding uniformity across the stack cross section will apply as for gases. The principal difference is that particles larger than a few microns have appreciable inertia and do not follow faithfully the streamlines and eddies of the gas. Abrupt transitions such as an elbow may tend to stratify particles according to size across a large duct. Good mixing in a turbulent system following a transition occurs 5 to 10 diameters downstream where mixing again is complete.[57] More data are needed on large diameter ducts regarding stratification of particles as a function of particle size. It has been observed that nonuniform distributions of particles of a given size occur when particles are swept in turbulent flow in a three-inch diameter tube.[58] This phenomenon, not yet clearly explained, appears to result from a balancing of reentrainment from the wall and flux to the wall which requires a greater concentration of particles in the annulus near the wall for some conditions. If this also occurs in large diameter ducts, it would necessitate simultaneous sampling from representative points on the cross section.

Another factor which influences the location of the sample withdrawal point is the distance downstream from a transition at which the velocity profile has stabilized. In one respect this distance may be regarded as identical to the position at which uniformity of particle concentration is achieved or restored. However, the two positions may not be identical, particularly in the complex, yet practical case in which two or more streams are being delivered from separate systems into the base of a single stack.

Velocity traverses must be taken at a section where the velocity profile has stablized so that the radial position at which the average flow occurs can be determined and used for measuring total gas flow. Locating the sample withdrawal point near the point selected for velocity measurements is recommended since the requirements of isokinetic sampling can be more nearly achieved if this is done.

The point at which the velocity profile has stabilized and achieved the aerodynamic symmetry for the circular conduit occurs at a minimum of five diameters from a disturbance, ten diameters is recommended. Hence, for stacks on the order of five to eight feet in diameter, the entry point for sampling should be a minimum of 25 to 50 feet above the breeching or change of flow from the horizontal to vertical. Withdrawal at this point permits sampling of reentrained particles from the wall in the lower portion of the stack, but cannot take into account changes in effluent composition which may occur from this point to the top of the stack.

A single entry probe with the collector element located immediately downstream of the probe could be installed in a stack at the proper point which represents the average particle concentration. During an emergency condition, however, the stack flow rate and the particle concentration may change drastically over those used in the design and location of the single entry probe. A multientry probe across the stack would compensate for the uncertainties accompanying the collection of a sample during emergency conditions. The particular advantages of the multientry probe for emergency monitoring and the added assurance of representative sampling dictates that this configuration be used in all effluent stacks.

The transport line from the inlet probe to the collector should be as short as possible. This requirement is necessary to insure that a representative sample is transported and is particularly important when particles one micron and larger are expected and flow is turbulent. If there are cases in which gases or submicron particles alone are present, the requirement of short delivery lines may not be so important. In the usual case, both particles and gases must be sampled, and delivery lines should be kept short, preferably no greater than a few feet from sample point to collector. Practical considerations of monitor placement may dictate otherwise, however. Abrupt changes in flow direction in any part of the sample delivery system must be avoided. The larger the particle, the greater the loss from deposition at sharp bends. Data to predict deposition losses in curved tubes are meager. Change in flow direction must be accomplished with sweeping bends with as large a radius as practical. Bend radii of less than 5 tube diameters should be avoided.[57]

It is beyond the scope of this discussion to specify or recommend actual sample flow rates, since their selection hinges so materially on the particular requirements established for the particular installation. There will be interplay and compromise between the sample airflow requirements established solely by the minimum quantity of radioactive material which must be detected during some interval. Other factors to be considered include pressure drop requirements for the collecting medium and isokinetic sampling requirements. The latter is of major importance, and the recommended range of inlet velocity to duct velocity ratio U/U_o is 1.0 ± 0.2.

All parts of the sampling delivery system must be highly corrosion resistant for the atmospheres in the system. Therefore, stainless steel is recommended. Plastic and rubber lines are not recommended because of chemical reactivity with halogens and possible electrical effects which may enhance deposition.

All parts must be fitted carefully prior to welding and any weld intrusion to the inside surfaces should be ground flush. Demountable joints in tubing must permit good alignment with minimal breaks in the wall surface continuity.

Condensation in all parts of the sampling system must be avoided. Thus, it may be necessary to heat the sampling system to temperatures equal to or slightly above those of the sampled gas.

In the stack release case, consideration needs to be given to the physical form of the material being exhausted. Because the form and the type of radioactive material can be highly variable, a three-stage sampling-detection system is recommended. The first stage consists of a filter system to collect particulates; ideally, such a system would remove no radioactive material in the gaseous or vapor phase. While in practice this is not the case, judicious selection of the filter should minimize the effect. A membrane filter with pore size $\leq 5\ \mu m$, sampling at approximately 30 liters per minute should prove adequate. The deposited radioactive material--essentially refractories--can be quantified by noting the rate of rise of the activity on the filter, making suitable correction for decay and nonequilibrium conditions.

The filtered air from the first stage is passed through an activated charcoal trap to collect halogens. Since ^{131}I is the nuclide of concern, some systems have been devised for direct measurement of the 364 keV photon associated with decay of this nuclide. However, the fractional abundance of ^{131}I relative to the other halogens varies with decay time[3,30,31,59] rendering this nuclide unsuitable for quantifying the halogen fraction unless appropriate corrections are made. Gross beta counting of the halogen fraction may be found useful, with examination of specific photon energies reserved for the laboratory.

After removal of particulates and halogens, the sample will contain only gaseous radioactive material, essentially all noble gases, which could be measured by a flow-through ion chamber. Although other methods, such as flow-through scintillators or Geiger-Mueller detectors can be used, the flow-through ion chamber may offer certain advantages, including simplicity of operation and design, and hence, is recommended.

Positive removal of the sample from the ventilation system is best accomplished by a constant displacement pump or other vacuum system which will maintain a constant flow, irrespective of pressure drop changes in the system. Ideally, a sampling system should provide a sample volume which is proportional to the volume exhausted through the stack. In practice, this is difficult to achieve, and a satisfactory alternative is to measure the flow rate through the stack and maintain a constant sampling rate.

IV.C.3. Containment Vessel Gaseous Monitoring

IV.C.3.a. Direct Monitoring of Noble Gases

Performance criteria for the Containment Vessel Noble Gas Monitoring System are presented in Section VI.A.3.b.

A rapid and reasonably quantitative estimate of the magnitude of the release into the containment vessel can be made by looking at the high energy photons from the noble gases. This is based upon an estimated 0.35 photons per disintegration in the region 2.15 to 2.65 MeV, as determined from the data in Table 1. A single detector, designed to measure only photons above 2 MeV could be used. In a large volume containment vessel with the detector at the center, semi-infinite field conditions prevail, and the following equation which is derived from information contained in the Rockwell[60] can be used to obtain the air concentration in $\mu Ci/cm^3$ of noble gases in the containment vessel:

$$\mu Ci/cm^3 = \frac{sGfk\mu}{\left(1 - e^{-\mu r}\right)} \qquad (1)$$

Equation (1) assumes a spherical containment vessel of radius r cm, and

μ = linear absorption coefficient for air for 2.15 to 2.65 MeV photons ($\sim 4.5 \times 10^{-5}$ cm^{-1}).

G = A geometry (or efficiency) factor for the detection system, in units of photons per count.

s = The count rate in counts per second.

k = A constant equal to 2.7×10^{-5} μCi second per disintegration.

f = A constant equal to the number of disintegrations per 2.15 to 2.65 MeV photons emitted (2.85).

Putting in the constants μ, f, and k, Equation (1) becomes:

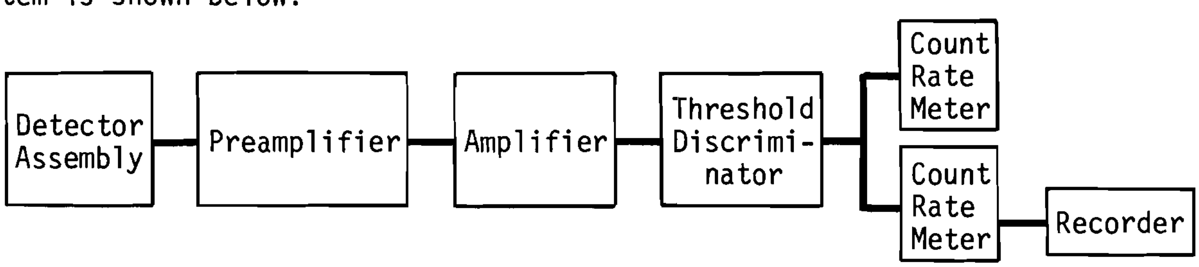
$$\mu Ci/cm^3 = \frac{3.4 \times 10^{-9}\ Gs}{\left(1 - e^{-\mu r}\right)} \qquad (2)$$

For very large values of r ($\geq 10^5$), the exponential approaches 0 and hence Equation (2) simplifies to

$$\mu Ci/cm^3 = 3.4 \times 10^{-9}\ Gs \qquad (3)$$

In most cases, however, r will be on the order of 10^3 to 10^4 cm, and hence the term $\left[1 - e^{-4.5 \times 10^{-5} r}\right]$ will range from 0.044 to 0.36. For this reason, Equation (2) should be solved directly for each individual case.

Thus, it appears the airborne fission product concentration can be quickly and easily estimated by a detector located in the containment vessel. The detector of choice for monitoring photons above 2 MeV energy is a NaI(Tl) crystal. Such detectors are rugged, relatively inexpensive, and have well-known characteristics. A NaI(Tl) detector for in-containment monitoring should be small, (1/2 in. x 1/2 in.) since sensitivity is directly proportional to the detector size. A block diagram for the system is shown below:



The preceding discussion suggests detector placement at or near the geometric center of a fairly large spherical containment vessel. In practice, this positioning may be difficult to achieve, and a suggested alternative would be to position the detector such that reproducible geometry conditions are met. The detector should be positioned such that the intact biological shield is between it and the core; this will minimize the effect of the fission products remaining in the core. Positioning the detector on the wall of a spherical vessel will enable the air concentration of noble gases to be estimated by:

$$\mu Ci/cm^3 = \frac{2\ \mu fksG}{1 - \frac{1}{2\mu r} + \frac{e^{-2\mu r}}{2\mu r}}$$

Similar calculations can be made for virtually any geometry; a particularly good summary of relevant equations is given in Rockwell.(60)

IV.C.3.b. Indirect Monitoring of Radioiodines and Particulates

Performance criteria for the Containment Vessel Radioiodine and Particulate Monitoring System are presented in Section VI.A.3.c.

Characterization of particulate and iodine radioactivity could best be accomplished by remote laboratory analysis of the atmosphere within the containment vessel. This, however, is not practical for emergency purposes. In-containment measurement of radioiodines and particulate radioactivity can best be accomplished by a system which permits the atmosphere within the containment vessel to be sampled and monitored continuously. Unlike the noble gas case, the in-containment monitor for particulate and iodine radioactivity should serve only as a semi-quantitative tool. There are many methods for assessing the airborne particulate and iodine radioactivity within the containment vessel. The high level ambient radioactivity will adversely affect the accuracy of most if not all systems wholly contained within the containment, and for this reason, the detector system should be well shielded, and preferably should be located outside the containment.

Obtaining a representative airborne particulate sample from a large volume using a single or few sampling locations requires that the gases and particles be well mixed in the vessel, and that the sample quality be modified inappreciably in transporting it to the collection and analysis point. In a large vessel filled with steam due to thermal convection, it is likely that over a period of a few minutes reasonably uniform mixing will occur.[19-21]

Sampler and collector design considerations are similar to the stack monitoring case, Section IV.C.2.b., and will be considered briefly for this case. The point from which containment air is drawn should be in the open, several feet from any large piece of equipment. There is no compelling justification to face the entry upward, downward, or horizontally, since isokinetic flow does not apply in the circumstances of sampling from a large static volume. In any orientation chosen, the entry port must be protected from the containment system spray, and fallout of large particles or droplets. A rain deflector cap supported four to six inches beyond the entry should suffice. Much of the uncertainty in obtaining a representative sample under the conditions in a containment vessel following an accident results from deposition in the sampling line between the entry point and the sample collection point. Condensation in the system will carry particles and vapors to the wall and must be minimized. Transport of elemental vapors such as iodine and bromine without loss is particularly difficult to achieve because of their chemical reactivity. In general, the deposition of halogen vapors is enhanced on copper, silver, bronze, and some plastic materials with which the halogens will react readily.

It is virtually impossible to select a delivery line and specify a material which would deposit a negligible quantity of the halogens in the length of line needed for application to a large reactor containment volume, and for a range of humidities and temperatures. Once the surface has an equilibrium deposit, the air concentration in the sampling line should stay reasonably representative unless large concentration changes in the sampled atmosphere occur. These can occur during the course of an accident. Reasonably good transmission can be expected in stainless steel lines. Glass-lined and epoxy-resin coated lines should prove to be suitable materials for sampling lines. A necessary condition is maintenance of sample temperature above the dew point upstream of the collector, thereby eliminating condensation. Provision for heating the sampling line is therefore highly recommended. Particle deposition in sample lines is a marked function of particle size and air velocity. By maintaining laminar flow, this problem is obviated. In general terms, deposition will be less for small particles in lines with laminar flow, but with sufficient velocity to preclude Brownian diffusion or settling in horizontal sections. Values for the Reynolds number, Re, should be kept ≤ 2000, and horizontal sections, bends and fittings should be kept to a minimum.

Adequate monitoring will be obtained by a constant air monitor using a two-step filter system. The first stage includes a particulate filter. This is followed by a second stage charcoal (or other halogen adsorbing material) cartridge or filter which effectively removes 99.5% of the halogens. Gross beta counting is suggested for the particulate filter and this can be accomplished by Geiger tubes, scintillators, or other detectors. This implies that the detector will be suitably shielded or that electronic or other means of discrimination will be employed to protect the detector from high ambient dose rates. Solid state detectors with high beta sensitivity and low response to the lower LET photon radiation may prove to be a superior detecting system. At this time, these are not sufficiently developed to recommend their use, but the technology is rapidly developing. Gross gamma counting is suggested for the halogen absorbing filter in a second suitably shielded location. This can be accomplished by a scintillator detector with a single-channel analyzer to monitor the ^{131}I photons.

IV.C.4. Environs Air Monitoring

Performance criteria for Environs Air Monitoring System are presented in Section VI.A.3.e.

Within the environs outside the site boundary, air monitoring can be restricted to particulate radioactivity and halogens. The noble gases, which would constitute most of the activity released in the early hours after the incident, are primarily an external hazard, and will be detected by ambient radiation monitoring equipment.

In general, air monitoring equipment should be of the continuous type, although spot samples with high volume samplers may be of some value to fill in gaps in geographical coverage by fixed units. The basic criteria for instruments for continuous air monitoring in the environs are similar to those provided for the air monitoring instruments in or near the facility, and should provide compatibility with those instruments. Woodward[61] has described a ten location air monitoring instrument which, with minor modification, could serve as the basic electronics package.

IV.D. MEASUREMENT OF LIQUID RELEASE

Performance criteria for the Liquid Effluent Monitoring System are presented in Section VI.A.3.f.

The measurement of a liquid release as the result of an accident does not present the same problem as the measurement of an airborne release, since the direction the liquid will take can be determined. In a major accident the airborne release will be the major consideration. Direct monitoring of the gross radioactivity in liquids is often done to detect cladding breaks or other abnormal situations for reactor control purposes, and many monitoring systems have been designed for this purpose. Generally, these are at best only marginally suitable to the greater demands of the emergency radiological situation. Similarly, liquid effluent monitors for low level routine conditions may be inadequate for the more rigorous emergency requirements.

Detection of radioactivity in liquid effluents is best accomplished by spectrographic techniques.[62-64] The high density of the liquid medium relative to air precludes measurement of beta activity, since the range of most fission product betas is less than one centimeter in water. To minimize interference from bremsstrahlung, pair production and scattered photons, a reasonably high lower level cutoff energy should be used, and

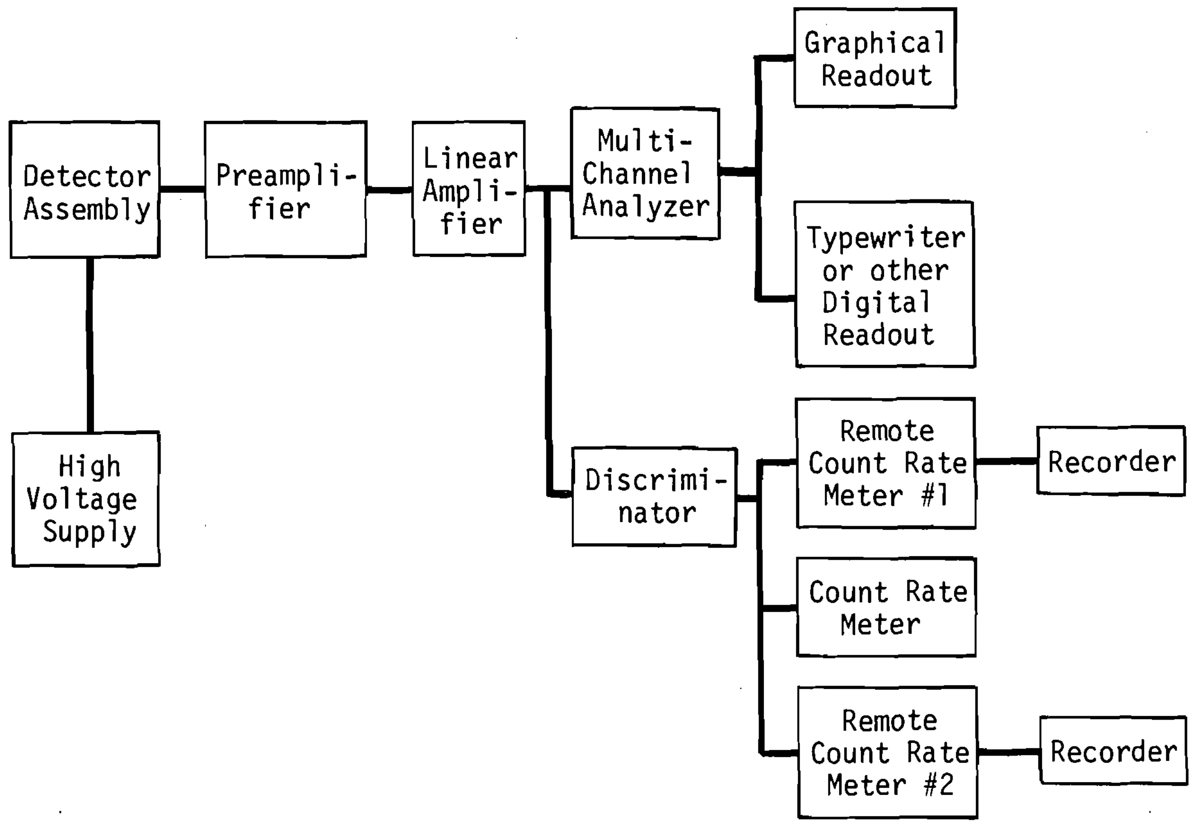
600 keV is the suggested level. Above this energy, approximately 0.5 photons per disintegration are emitted by nuclides in each of the groups cited in Section II. Thus, irrespective of the solubility or fraction of each group released to the liquid, a reasonably good estimate of the total activity can be made by measurement of the photons with energies greater than 600 keV.

The preferred detector is a small NaI(Tl) crystal, appropriately sealed and placed within the liquid medium, or alternatively placed such that it looks directly at the effluent liquid stream. However, other detection systems such as proportional counters or semiconductors can be used if these can meet the sensitivity and ruggedness requirements; in certain cases, particularly where high temperatures may be encountered, these may be superior. Moreover, these give superior resolution for spectroscopy. The detector can be located in-line or immersed in a holding tank or pond or it can be located external to but directly on the line or tank. There are advantages to each location, and the decision with respect to placement must be based on considerations specific to each reactor, bearing in mind the advantages and liabilities of each.

Direct immersion in tank or in-line generally provides improved geometry, minimal error from source nonuniformity, and minimizes ambient radiation interference from the reactor or other nearby sources. However, immersion of the detector requires special encapsulation, particularly if the liquid is corrosive or if the temperature is beyond the range of the detector. Access and maintenance may be rendered more difficult and flow interruption and line size may impose additional limitations. A bypass line may offset some of the liabilities, (e.g., the fluid can be cooled), but at the same time may reduce some of the advantages of direct in-line monitoring.

Monitoring off-line, while generally providing poorer geometry and reduced sensitivity, permits greater flexibility in placement along with increased ease of maintenance. However, shielding requirements may be increased, and in addition, corrections for wall effects may be required.

As can be seen from the block diagram shown below, spectroscopy capability may be included to provide a means of specific nuclide identification and quantification.



This capability may be of particular importance if activity can be released to an estuary or lake where it could be rapidly incorporated into a community water supply. The validity of an underwater spectrometry system using a large NaI(Tl) detector has been demonstrated by Riel and Duffy.[63]

IV.E. MEASUREMENT OF AMBIENT RADIATION FIELDS

Performance criteria for the Ambient Radiation Monitoring System are presented in Section VI.A.3.g.

In most postaccident monitoring situations, portable hand-carried radiation survey meters will serve as the primary means of establishing the ambient radiation field at designated locations. However, appropriately placed remote area monitors can provide valuable information about the radiation fields in or near the reactor facility which might otherwise be unobtainable because of the high radiation levels and concommitant personnel hazards.

IV.E.1. Containment Vessel and Reactor Building Ambient Radiation Monitoring

The use of remote area monitors for measuring ambient radiation fields should be limited to locations in the interior of the reactor facility most likely to be affected by radiation incidents. Typical locations would include the containment vessel, control room, fuel handling and storage areas, and in hallways and laboratories. Specific locations will vary from site to site, but in general, a dozen detectors should suffice. Specific placement should be dictated by local shadow shielding, potential for physical damage, radiation field mapping requirements, and distance from the source. This latter item can be of major importance. For example, if the source is at floor level and the detector is placed some 15 or 20 feet overhead, beta radiation will be virtually completely shielded by the air, and hence an erroneous indication of the ambient field at the location of interest may result. If the erroneous data are used for evaluating reentry possibilities, consequences could be severe.

Differentiation of the penetrating-nonpenetrating portions of the dose contribution is not commonly accomplished, but in the emergency situation this may be vital. Area monitors should be designed to provide separate indication of the ambient beta plus low energy photon fields and high energy photon fields within the reactor facilities, and should also have a very wide range. Virtually any type of detector can be used, but ionization chambers and possible Geiger-Mueller detectors appear to offer the greatest advantages. To obtain high range capability with the latter, provision must be made for operation in the current mode.

Examination of the photon flux as a function of energy at various times after fission reveals that an appreciable fraction of the photons have energies below 100 keV.[3,30,31,60] To this must be added any low energy photons from scatter, activation products, bremsstrahlung, and perhaps fuel. The exact composition, or even a reasonable estimate, of the photon spectrum cannot be determined by calculation or theoretical means; however, data from a simulated loss of water accident showed an effective photon energy of approximately 150 keV, with a preponderance of photon energies below 250 keV.[65] Hence, any detector system used should have fairly flat photon energy response. Similarly, the detector should have thin walls to provide improved beta sensitivity. A suggested maximum wall thickness is 15 mg/cm^2; this will permit beta particles with energies greater than 100 keV to penetrate the detector. The detectors placed within the containment building will require thicker walls in order to withstand possible pressure surges to 50 psi. These detectors will not have proper beta sensitivity and corrections will be required when these detectors are utilized.

Beta-photon differentiations can be relatively easily obtained by two detectors, one bare and one shielded with approximately 1 gm/cm^2 of a low Z plastic such as polyethylene or polystyrene. These or similar plastics are recommended because of their well-known properties, availability, low cost, workability, and radiation resistance. For example, a polyethylene shield 1.0 gm/cm^2 thick would be opaque to beta particles with energies below about 2 MeV, would produce essentially no bremsstrahlung, and would attenuate low energy photon response only slightly since "buildup" or scattering within the shield would compensate to some degree. The estimated response of an unshielded detector and the estimated response of the same detector shielded with 1.0 gm/cm^2 of polyethylene is shown in Figure 12. As can be seen, the effect of the shield is minimal below about 30 keV.

Although virtually any detector with flat beta and a flat photon response can be used, an unpressurized air ionization chamber would probably prove to be the most satisfactory. Ion chambers are fairly simple, inherently stable and rugged, have broad range, have minimal electronics and other supporting requirements, and can be made to have flat

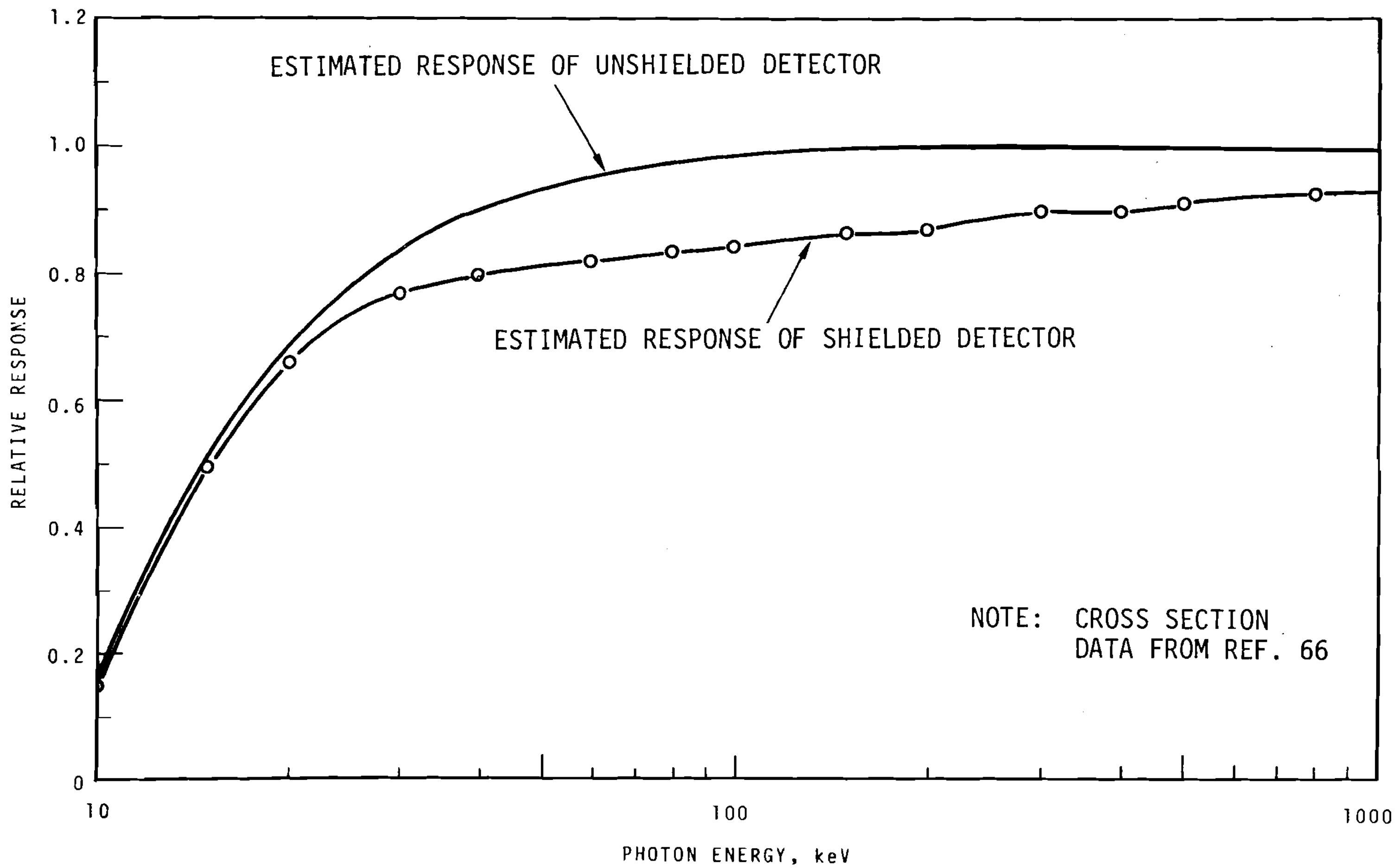


FIGURE 12. Photon Attenuation of 1.0 g/cm^2 Polyethylene shield

photon energy response with relative ease. Similarly, appropriately designed and constructed ionization chambers can provide a good measure of the beta dose in air.

Although ion chamber detectors are preferred, the use of other detectors or systems with flat response, either inherent or by appropriate shield flattening, is not precluded. A system of tissue equivalent detectors could be used, provided that these give the absorbed dose to the surface of the body or to the basal epithelial layer of the skin, as well as the absorbed dose to either the 1 cm soft tissue depth (gonads) or 5 cm depth (bloodforming organs).

Electronics used with the ion chamber detectors should reflect the latest technology, and should be solid state throughout. Although many commercial ion chamber circuits make use of electrometer tubes, the technology of semiconductors is sufficiently advanced to permit wholly solid state electronics, with the exception of the detector. MOS-FET circuitry can be used in place of electrometer tubes, eliminating the warm-up requirements, drift, and similar problems of instability associated with electrometer tubes. Electrometer tubes are much more radiation resistant than MOS-FET circuitry and may be required in locations such as the containment vessel where the integrated dose could be large.

IV.E.2. Environs Ambient Radiation Monitoring

The use of remote area monitors for measuring ambient radiation fields in the environs also could be worth while. The ambient radiation field will be produced by mixed fission products from fallout onto the ground or other horizontal surfaces. A distinct feature of the ambient radiation field will be its unevenness, in part caused by terrain factors, vegetation and shielding from structures, as well as micrometeorological conditions. The radioactive cloud from either a burst or continuous release could result in a significant ambient field, which, at least at early times after the occurrence, could be predominately from the noble gases and their associated high energy photons.

The number and choice of locations is dependent on several factors including size of site, analysis of accident potential, and terrain and population features. Logical locations might be site boundary, population center, and individual residence in potential direct path of a plume. In a multifacility reactor site, these instruments could serve all of the reactors.

The characteristics of the ambient field in the environs is highly dependent on the specific location of the measurement as well as the time after the occurrence and the various fractions released. An appreciable fraction of the dose contribution may be from beta or low energy "non-penetrating" photon radiation, and to adequately characterize this field, a thin-walled detector is required. However, the high energy photons from the noble gases will also be major contributors to the total dose, and for monitoring will require a thick-walled detector to achieve charged particle equilibrium. Hence, two individual detectors would be necessary to adequately characterize the total ambient radiation field. The need for beta-gamma discrimination, however, is not as apparent for this case.

Dose integration should be considered for the ambient monitors located in the environs. This can be readily accomplished by signal splitting, with a portion of the signal used for dose accumulation measurement. Other convenient integrating techniques are available as well. Integrating capability may permit a rapid assessment of population dose for a limited area without the need for retrieval and processing of thermoluminescent or other dosimeters.

IV.F. GENERAL DESIGN CONSIDERATIONS FOR INSTALLED RADIOLOGICAL INSTRUMENTATION

General Performance criteria for Installed Radiological Systems are presented in Section VI.A.1.

Much of the total emergency radiation monitoring instrumentation package will consist of installed or fixed instrumentation at a specific location. There is considerable functional commonality of instrument modules which will permit design and use of many interchangeable units. Where possible, functional entities, e.g., power supplies, circuit modules, units and components should be interchangeable, thereby providing demonstrable practical advantages, including:

- Smaller parts inventory requirements.
- Rapid *in situ* repair capability by module or plug-in part replacement, permitting functional capability to be maintained with relatively inexperienced and untrained personnel.
- Reduced training requirements, since maintenance personnel need be familiar with fewer basic units.
- Minimization of design and installation cost.

The overall system should be capable of operating both on 117 volt, 60 Hz AC line and secondary or emergency power sources. The latter can either be a secondary AC generator designed to come on in the event of a power failure, or a DC system using batteries maintained by a trickle charge.

Electronic components should conform to the specifications for, and be compatible with, the standard nuclear instrument modules established in TID-20893, Revision 2,[67] thus ensuring a basic standard. Insofar as is practicable, criteria stated below refer to the overall system including the detector, rather than a specific component or unit. The criteria are not intended for portable radiation instruments or meteorological instrumentation. Generalization will allow for some choice of modules, units and components, and minimize "locking in" on specific designs.

Electronic components should reflect the latest technology, and a three to five year design lifetime for modules is not unreasonable when considered in the light of technological progress. To that end, electronic apparatus should make maximum use of solid state devices, and in particular, integrated circuits. Plug-in circuitry, ease of maintenance, and appropriate human engineering are vital. As an example of the latter, basic safety features, mechanical as well as electrical, must be incorporated into each system as a whole. Test points and switches should be appropriately marked, and the requisite waveforms, voltages, or other parameters should be called out at the test point as well as in service manuals.

Overall system accuracy should be within ±40% at the 95% confidence level as determined with a calibration source, with a precision (reproducibility) of ±10% for any single level. The entire system should be unaffected by power surges, external rf or magnetic fields, and AC induced fields and transients, and to best achieve this independence, a separate instrument power circuit is recommended. Isolation transformers, while effective in many instances, can be adversely affected or even rendered inoperative by extraordinary demands of a major accident.

The instrument system inclusive of the detector should not paralyze--i.e., indicate downscale--in radiation fields greater than the intended range. Readout should be accomplished without recourse to manual range changing, since in the emergency situation adjustment of the instrument system may be impractical. Automatic range changing with linear readout, logarithmic readout, or digital readout are acceptable methods of presentation. Two central readout stations are recommended: one in the reactor control room, and the second in the emergency control center. The emergency control center should be a preselected location physically removed from the reactor facility and situated and designed for access and use in the emergency situation. In addition, a readout should also be provided at the detector location. This readout is of value for field calibration and could in many instances be of value in the emergency situation as well.

Instrument systems will most likely be included in areas of substantial ambient background radiation, therefore they should be free of extra-cameral effects, possibly to levels of 10^5 to 10^6 R/hr. Radiation-hardened components are strongly recommended, and the overall system should be cap- of withstanding an exposure to 5×10^5 R without breakdown.

Neutron effects can be minimized by appropriate shielding and judicious choice of materials with small cross sections for neutron interactions, particularly with respect to activation and (n,p), (n, α) and other neutron produced charged particles. Protection from magnetic and rf fields, if required, can be afforded by mu metal and/or copper screen enclosures.

Weather protection and temperature regulation is also required; temperatures should be kept at 20 ± 5°C to minimize the effects of temperature on the system response. In particular, overheating of a system must be avoided to prevent damage to sensitive elements. Although some systems should be enclosed in weatherproof, temperature controlled buildings, they nonetheless should be capable of operation under varied environmental conditions in the event of power failure, earthquake, etc. Thus, the operating temperature range of the equipment should encompass the extremes anticipated. Where the instrumentation may be exposed to ambient outside temperatures, the 50 year extremes should be applied. Temperature compensation for the detector or other sensitive components may be required.

V. AMBIENT RADIATION AND CONTAMINATION SURVEY INSTRUMENTS CHARACTERISTICS

Ambient radiation and contamination survey instrument measurements are intended to supplement those obtained from fixed instrument systems and also to aid in the protection of operating personnel during efforts to stabilize the emergency.

Characteristically, these instruments need to be highly flexible and yet rugged in order to function as desired and withstand the punishment they may receive.

V.A. PORTABLE DOSERATE AND CONTAMINATION MONITORING

Performance criteria for Doserate and Contamination Survey Instruments are presented in Section VI.C.1.

Monitoring on an emergency basis following a reactor accident normally will be for mixed beta and photon radiation from ambient air and surface contamination. Neutrons will be absent except in rare cases. Alpha contamination, if present, will be greatly overshadowed by the fission products. Hence, the problem reduces to one of field monitoring for beta and gamma radiations.

The breadth of application of portable survey meters may require unusual design demands or several instruments to accomplish the tasks at hand. Two basic design concepts: (1) an instrument designed and used for a specific purpose, or (2) a universal electronics package designed to accept a variety of detectors, and, possibly, readouts. Each has merits, and has been applied in the field. Unfortunately, each also has serious drawbacks. For example, the individual instrument approach may require a relatively large number of different instrument types, and may prove expensive and impractical from a logistics point of view. The "universal" electronics package requires additional sophistication on the part of the user with respect to detector selection and interpretation of readout; in addition, some compromises in individual detector capability may have to be made to achieve a high degree of universality.

It is possible to go one step beyond and consider a more truly universal design: A single instrument which will provide the necessary broad range for ambient radiations, beta-photon discrimination, contamination monitoring capability, and, possibly, an integrate mode. Such an instrument is not beyond the current state-of-the-art, and with solid state circuitry would not be prohibitively heavy. Recent commercial trends have been to instruments having these capabilities.

In recognition of the fact that different sites and locations may have different needs, both single purpose and "universal" instruments are included in the following considerations. It should be noted, however, that the selection of a multipurpose or "universal" type instrument is usually recommended, since the advantages would seem to far outweigh the disadvantages.

Instrument design and evaluation can be considered in the context of three broad areas: mechanical, electronic, and radiological.[68,69] Mechanical features refer to physical construction, which of course must be rugged and of good quality. The instrument must be designed for hard usage, and therefore should be capable of withstanding shock and should be operable in weather extremes or other similar situations.

An important aspect of portable survey instruments, often overlooked, is human engineering, which should include consideration of safety hazards, along with ease of handling, readout, and servicing. Typical safety hazards include sharp edges, inadequate grounding, and other shock hazards. The shape, size and weight of the instrument are important and obvious factors in ease of handling, and are seldom overlooked. The general external appearance of an instrument including location of switches and their switching arrangements alone can affect its acceptance by monitoring personnel. Consideration should be given to use of portable instruments by personnel wearing gloves and other personal protective clothing, to use of portable instruments at night or in inclement weather, and to the ease of decontamination.

Ease of servicing is an important consideration. Batteries should be readily accessible without removal of other components or a large number of fasteners; this factor alone can save several maintenance man-hours per year. Low cost, common batteries are highly desirable and are strongly recommended; particularly if field replacement is required. Standard flashlight type batteries such as the D cell and 9 volt transistor batteries, because of their low cost and availability, are perhaps the best choice. Batteries should meet the specifications published by the National Bureau of Standards.[74] Instruments so designed also can be compatible with standard mercury of alkaline cells. A carbon zinc battery will not operate below 0°C for more than a few hours without freezing. If instruments are to be operated in locations where temperatures below 0°C can be expected, alkaline batteries should be used for continued operation. Circuit boards, accessible from both side and with labeled components can also provide significant reductions of maintenance costs. Circuit boards should be keyed to prevent inadvertent erroneous positioning in the socket.

Electronic components should reflect the latest technology and highest reliability possible. To this end, solid state devices should be used wherever possible to minimize current drain and reduce weight. Electrometer tubes with their inherent instability, long warmup time and current drains are not recommended, except in cases where extreme radiation hardness is required. The MOS field effect transistor circuit is far superior with regard to current drain and stability, however, it is far inferior with regard to resistance to high radiation exposure.

Electromagnetic radiation of many kinds can cause unusual effects and spurious response. The circuitry, rather than the detectors, is more commonly affected. In most cases, well designed circuits with good electrical shielding will not be affected by electromagnetic fields.

The radiological response of the instrument system is, or course, the primary consideration. Survey meters should be responsive to both beta and photon radiation, and should provide a reasonably accurate measure of doserate, particularly if the readings obtained from them will serve as the basis for rescue work. The method outlined in Section IV.E.1. for ambient radiation monitors, in which a 1 gm/cm^2 low Z shield is used for beta-photon discrimination, is readily adaptable to portable survey meters. For rate meters, and in particular those which may be used as the basis for rescue efforts, accuracy is necessary[70,71] along with an upper limit of at least 5 to 10 kilorads per hour.[72,73]

Lower level capability, perhaps down to levels of a few tenths of a millirad per hour may be required for environmental evaluation purposes. To monitor this wide range, which extends over eight orders of magnitude, a single detector may not be adequate.

Portable survey meters can be made with an integrate mode in addition to the rate mode. An instrument with this capability could be used in lieu of or in support of immediate readout or alarm pocket dosimeters. The integrating range for photon exposure and beta dose should be at least 10^3 R and rem, respectively, and should span at least four decades with a variable presettable alarm point. The alarm should be settable by an external switch and the alarm should have the appropriate frequency and sound level so that it can be heard distinctly at least 50 centimeters from the instrument.

V.B. MOBILE DOSERATE AND CONTAMINATION MONITORING

Performance criteria for Doserate and Contamination Survey Instruments are presented in Section VI.C.1.

Portable beta-gamma monitoring instruments, as described in the preceding section may well serve satisfactorily as mobile instruments, if recording capability exists and if a special mount for the probe is provided. These conditions could permit safe operation of a surface vehicle such as a jeep or boat by a single individual while continuously recording instrument data. The conditions or requirements described for portable instrumentation should also apply for instruments used in mobile monitoring. If these are to be used in an airplane, they should be designed to operate properly at an altitude of 5000 feet over the surrounding terrain. Each separate component of the mobile instrument system should weight less then 50 pounds.

V.C. PORTABLE AIR MONITORING

Performance Criteria for Portable Air Samplers are presented in Section VI.C.2.

Emergency monitoring of airborne radioactive materials, if accomplished in the field, is often done with ambient radiation monitoring instruments calibrated or otherwise used in conjunction with grab samples.[36,75-78] A few air samplers with self-contained power supplies have been described which enable a sample of particulate ratioactivity to be obtained in the field.[79-82] In addition, several self-contained air samplers of the 'personal' type also have been described.[83-88] However, there have been essentially no wholly self-contained portable air or liquid radioactive material monitors designed for emergency purposes, with the possible exception of the survey meter adopted by Block and co-workers.[71,72]

Consideration of the potential application, need, and capability requirements leads to the conclusion that the concept of Block and Beard[79] could be adapted to direct monitoring of airborne radioactivity in the field. Such an adaptation appears both practical and logical, and provides for the direct examination of a filter with a portable survey meter. In fact, the net result is essentially a portable air sampler used in conjunction with a portable survey meter. The survey meter should of course, meet the requirements described in V.A., and should be mechanically and otherwise compatible with the air sampler portion. Logically, the two parts should be designed to function as an integral unit, but with provision made for detached, independent operation. Hence, each would have its own source of power.

The air mover-sampler will require considerably more power than other portable electronic instrumentation. Power requirements for a sampling rate on the order of 20 liters per minute is several watts. Such power levels cannot be conveniently provided with D cells, and necessarily the use of Ni-Cd wet cells or similar high efficiency-low weight batteries will be required. Rechargeable batteries are recommended, with provision for recharging from a standard 117 V, 60 Hz AC, or a 12 V DC automotive system is recommended.

V.D. DETERMINATION OF PERSONNEL EXPOSURE OR DOSE

Performance criteria for Direct Reading Dosimeters are presented in Section VI.C.3 and performance criteria for Personal Alarm Dosimeters are presented in Section VI.C.4.

There are a wide variety of devices which integrate exposure or dose. From the standpoint of the emergency only those devices which provide for a direct, instantaneous readout without disturbing the operation of the device or the accumulation of information will be considered. Hence, for all practical purposes, photographic and luminescent devices are excluded, since these require special readout equipment and, in addition, readout may erase or terminate the usefulness of the device.

With the exclusion of photographic and luminescence systems, essentially only electronic methods remain. Pocket ionization chambers (PICs), survey meters with integration capability which were described in Section V.A. and personal alarm dosimeters (PADs) characterize this group.

Personal (or, alternatively) pocket alarm dosimeters are a hybrid pocket dosimeter and integrating survey meter. Several have been described in the open literature over the past few years.[89-94] These have been made available primarily as a result of the development of miniature components. Although in many respects these have not yet been developed to their full potential, they may be superior to either the PIC or integrating survey meter for rescue purposes. In general, these should meet the requirements described for integrating survey meters.

Direct reading pocket ionization chambers would appear to be the least suitable for the emergency situation in general and rescue work in particular, because of the absence of an alarm capability and the difficulty in readout. Pocket ionization chambers should generally conform to the standards and criteria put forth by the American National Standards Institute.[95]

VI. EMERGENCY INSTRUMENTATION CRITERIA

The Emergency Instrumentation Criteria presented in this section are primarily performance criteria. Specific instrument systems, components or individual instruments which should meet these criteria are discussed in Sections IV and V. Throughout these criteria four verbs have been used to indicate the degree of rigor intended by the specific criterion. "Shall" and "Will" indicate that strict application of the criterion is possible and is considered necessary to assure the instrumentation or systems will perform as needed during an emergency. "Should or "Would" indicate that the application of the criterion is desirable.

Some of the radiological and environmental criteria are severe and calibration or certification are beyond the capability of individual nuclear facilities. Therefore, it is important that these instruments, systems or individual components be thoroughly tested at least once under all extreme conditions of operation to assure conformance with the criteria.

VI.A. RADIOLOGICAL INSTRUMENTATION SYSTEMS

VI.A.1. General Criteria for Installed Radiological Systems

1. The system shall have an internal electronic calibration check, which shall check operation of all circuitry other than the detector.

2. The system shall be fail-safe; in the event of a malfunction or failure, an internal audit circuit shall be activated and transmit an appropriate signal to a central manned location.

3. The system shall be capable of operation on 117 V 60 Hz AC, and shall be unaffected by voltage or frequency changes of ±20%. Emergency power capability shall be included in the design and installation, and shall be automatically implemented when required, with no more than a six second delay.

4. When responding to levels in excess of the maximum specified range, the instrument should not paralyze and the readout signal shall remain full upscale.

5. Switches and other controls shall be protected to prevent inadvertent deactivation or operation of system.

6. Overall system accuracy shall be ±40% at the 95% confidence level over the entire operating range, with precision ±10% for any single measurement level.

7. Overall system response time from 0 to 90% of full reading shall be $\leq$2 seconds.

8. There shall be no deleterious effect to the system from radiofrequency and microwave exposure to 10 mW/cm^2, photon exposure to 5×10^5 R, referenced to the energy range between 0.8 - 1.2 MeV, and from electrostatic charges with potentials to 10,000 volts.

9. The operating temperature range of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 year extremes shall be applied.

10. For the operating temperature range the temperature coefficient shall be $\leq$0.5% per °C and it should be ±15% over the entire range.

11. The instrument system shall be unaffected by relative humidities from 5% to 95% over the designated temperature range.

12. The system shall be able to withstand mechanical stress equivalent to a peak overpressure of 15 psi. If located within the containment facility, the system shall be able to withstand mechanical stress equivalent to a peak overpressure of 50 psi.

13. Logarithmic or digital readout should be employed. If multiple ranges are used, automatic range changing shall be provided. Manual adjustment of range shall be unnecessary.

14. Readout capability shall be provided in the control room and at least two other physically separate locations, one of which shall be the emergency operations center, and the other at or near the detector.

15. All units of similar function, including detectors, electronic modules, readout and display devices and power supplies, shall be wholly interchangeable within type.

16. Except as noted, the electronics shall meet the specifications for and be compatible with the AEC standard nuclear instrument modules,(67) thus ensuring a basic standard, ease of maintenance, and providing interchangeability and compatibility.

17. Electronic and other supporting components should reflect the latest technology with solid state (i.e., transistorized) circuitry incorporated throughout, as practicable. The use of integrated circuits should be considered.

18. All modules shall be accessible for test without removal from the circuit. Plug-in type units should be considered.

19. The instrument system shall be equipped with an alarm capable of being externally set to alarm at any point over the stated range. The alarm should be both audible and visible, and should be capable of reset without removing the instrument from service.

VI.A.2. General Criteria for Gaseous and Particulate Sampling

1. The system shall be designed to remove on a continuous basis, a representative sample.

2. The location for sampling should be close to the point of release.

3. Particulate-generating gas phase reactions, corrosion, or release of contaminants, should be absent downstream of the sampling point.

4. When sampling a stack, the sampling point shall be no less than five duct diameters and preferably should be at least 10 duct diameters downstream from any injection point or point of turbulence or transition. A multi-entry probe shall be used for sampling in the duct or stack.

5. Sampling conditions should approach isokinetic. The inlet velocity to duct velocity should be 1.0 ± 0.2.

6. Sampling lines shall be kept short. The distance from sample point to collector should be less than 10 feet. Sample line bend radii shall exceed five sampling line diameters.

7. The sample delivery system shall be corrosion resistant and designed for streamline flow with no right angles or sharp bends. Stainless steel should be used for construction and plate out of radioactive material should be less than 5%.

8. A constant sample flow rate shall be used and a constant displacement pump should be used as the air mover. An appropriately calibrated airflow meter shall continuously verify flow rate, and shall be accurate to within ±20%.

9. Particulate radioactive material shall be removed by membrane filters with pore size ≤ 5 μm, having an efficiency of $\geq 99.5\%$ for particles with diameters ≥ 0.3 μm.

10. Charcoal impregnated with potassium iodide shall be used to sample airborne radioiodines. A minimum of 99.5% removal shall be required with a minimum 24 hour retention at the maximum concentrations expected. The charcoal medium should follow the particulate filter in the same sample stream.

VI.A.3. Specific Criteria for Radiological Instrumentation Systems

VI.A.3.a. Criteria for Plume Detection Instrumentation

The criteria listed below are in addition to those presented in Section VI.A.1.

1. The detector system shall consist of six NaI(Tl) crystals placed in circular array at ground level 60° of arc apart 100 meters from the reactor.

2. The detectors should be hermetically sealed NaI(Tl) crystals, typically 3" x 3". The photomultiplier tubes shall be an integral part of detector assembly.

3. The photomultiplier tube shall be shielded from rf and magnetic fields.

4. The detection range for fission gases shall be 10^{-2} to 10^{3} Ci per meter of plume length, based on detection of photons above 2.0 MeV.

5. The detector resolution shall be $\leq 10\%$ FWHM at 2.5 MeV.

6. The coincidence sum peak from ^{60}Co shall be used to calibrate the system. Each detector shall be checked quarterly with a source, and calibration or maintenance shall be performed when indicated.

VI.A.3.b. Criteria for Containment Vessel Noble Gas Monitor

The criteria listed below are in addition to those presented in Section VI.A.1.

1. The detector shall be a hermetically sealed NaI(Tl) crystal. The photomultiplier tube shall be an integral part of detector assembly.

2. The photomultiplier tube shall be shielded from rf and magnetic fields.

3. The detection range for noble gases shall be 10^{-9} to 10^{-2} Ci/cm^3 assuming detector immersion in a semi-infinite sphere and based upon detection of photons above 2.0 MeV.

4. Detector resolution shall be $\leq$10% FWHM at 2.5 MeV.

5. The coincidence sum peak from ^{60}Co shall be used to calibrate the system. The system shall be checked quarterly with a source, and calibration or maintenance shall be performed when indicated.

VI.A.3.c. Criteria for Containment Vessel Radioiodine and Particulate Monitor

The criteria listed below are in addition to those presented in Sections VI.A.1. and VI.A.2.

1. Detection of particulate radioactivity should be on the basis of beta counting and iodine radioactivity should be on the basis of gamma counting.

2. For particulate radioactivity the minimum detection range shall be 10^{-10} to 10^{-3} Ci/cm^3 referenced to betas from ^{90}Sr-Y.

3. For radioiodine, the detection capability shall be 10^{-10} to 10^{-3} Ci/cm^3 referenced to gammas from ^{131}I.

4. The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated.

VI.A.3.d. Criteria for Stack Effluent Monitor

The criteria listed below are in addition to those presented in Section VI.A.1 and VI.A.2.

1. The detection capability for particulate radioactivity shall have a minimum range of 10^{-10} to 10^{-3} Ci/cm^3 referenced to ^{90}Sr-Y, and based on gross beta detection. This range shall overlap the range of stack monitoring instrumentation used for routine or non-emergency monitoring.
2. For radioiodines, the detection capability shall be 10^{-10} to 10^{-3} Ci/cm^3 referenced to ^{131}I, and based on detection of the gamma energy of interest. This range shall overlap the range of non-emergency instrumentation used for monitoring radioiodine in stack releases.
3. For the gaseous fraction, detection capability shall be 10^{-9} to 10^{-2} Ci/cm^3. A flow-through ion chamber for gross beta radioactivity should be used for the detector system.
4. The detectors shall be suitably shielded from external radiation from the reactor operation or a release into the containment vessel. If a flow-through ionization chamber is used for detecting gaseous radioactive material, approximately 15 cm (6 inches) of lead should be used if the detector is within the containment vessel. For beta detectors, electronic discrimination should be used, but if this is not feasible, shielding may be used.
5. The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated.

VI.A.3.e. Criteria for Environmental Air Monitor

The criteria listed below are in addition to those general criteria presented in Sections VI.A.1 and VI.A.2.

1. The system shall be designed to take on a continuous basis a representative sample of the ambient air. The preferred sampling

location is at one meter above ground level, in a location free from unusual micrometeorological or other conditions (e.g., proximity of large buildings, vehicular traffic) which could result in artificially high or low air concentrations.

2. Direct sampling with no lines upstream of the sample medium is greatly preferred.

3. The sample collector shall be easily readable in place with portable monitoring instruments and removable for subsequent laboratory analysis.

4. The measurement capability for particulate activity shall have a minimum range of 10^{-6} to 10^{-1} Ci/cm^3 gross beta referenced to ^{90}Sr-Y. This range shall overlap the range of instrumentation used for routine or nonemergency monitoring.

5. For radioiodines, the measurement capability shall be 10^{-7} to 10^{-2} Ci/cm^3 referenced to ^{131}I. This range shall overlap the range of routine or nonemergency instrumentation used for monitoring radioiodine in the environs.

6. The instrument system shall be protected from the external environment, and shall be housed in a locked facility to afford a measure of security from accidental or willful damage or tampering.

7. The entire system operation shall be checked at least quarterly and calibrated and maintained when indicated.

VI.A.3.f. <u>Criteria for Liquid Effluent Monitor</u>

The criteria listed below are in addition to those general criteria presented in Section VI.A.1.

1. The detector system should consist of a small (typically an 0.5 x 0.5 in. right cylindrical) NaI(Tl) crystal.

2. The detector and photomultiplier shall be optically coupled and hermetically sealed into an integral container.

3. The minimum thickness of the material around the detector shall be at least 400 mg/cm^2; preferred thickness is 1000 mg/cm^2.

4. The detector resolution shall be ±12% FWHM for the 1.17 MeV photon peak associated with ^{60}Co decay.

5. The photomultiplier tube shall be provided with mu metal or other shielding to obviate the effects of magnetic fields.

6. The detector shall be capable of operating completely submerged.

7. The system shall be capable of detecting gross radioactivity in aqueous liquids over the range 10^{-9} to 10^{-4} Ci/cm^3, referenced to photons with energies greater than 0.6 MeV, and assuming 0.5 photons per disintegrations.

8. If the system is used to monitor a liquid stream, a flow meter, accurate to within ±20%, shall be provided. This flow meter should also have remote readout capability; integrating capability should be considered.

9. If the system is used to monitor a static or nearly static volume of liquid, provision shall be made to accurately monitor liquid volume, or alternatively, liquid level.

10. The photon peak at 1.17 MeV from ^{60}Co shall be used to calibrate the system. The system shall be checked quarterly with a source and calibration and maintenance performed when indicated.

VI.A.3.g. Criteria for Ambient Radiation Monitoring Instrumentation

The criteria listed below are in addition to those presented in Section VI.A.1.

1. The system shall be capable of detecting separately dose contribution from beta and low energy photon radiation, and the high energy photon radiation.

2. Photon energy dependence shall be ±20% over the range 30 keV to 3 MeV.

3. Beta energy dependence shall be ±30% over the range 0.1 to 3 MeV.

4. The system shall have an internal electronic calibration check and an internal radioactive check source for the detector. These shall be capable of remote operation, i.e., the check shall be capable of being made from the Emergency Control Center. Calibration and operating checks shall be made monthly and recalibration and repair accomplished when indicated. If integrating capability is provided, this feature shall be reset at the time of calibration check.

5. Detector placement shall be such that a representative measurement of the ambient field is obtained. The detector shall therefore be protected from fallout accumulations, shadow shielding, and similar effects. The recommended detector height is one meter above ground level in the environs.

6. If the ambient radiation monitor is to be used in the containment vessel the following shall apply:

   - The detection range for photons shall be 1 to 10^6 R/hr.
   - The detection range for beta radiation shall be 10 to 10^6 rad/hr.
   - Extracameral response shall be undetectable in photon fields to 10^6 R/hr referenced to 1 MeV energy, beta fields providing an air dose rate of 10^6 rad/hr referenced to 2 MeV, either singly or concomitantly.

7. If the ambient radiation monitor is to be used in the reactor building or environs the following shall apply:

   - The instrument system shall have a measurement range for photons of 10^{-3} to 10^4 R/hr. If an integration mode is provided, its operation should be simultaneous with the rate mode and its range should be 10^{-2} to 10^4 R.
   - The measurement range for beta radiation shall be 10^{-2} to 10^{-4} rad/hr. If a simultaneous integration mode is provided, its range should be 10^{-2} to 10^4 rad.

- Extracameral response shall be absent in photon fields to 10^4 R/hr referenced to 1 MeV energy, and beta fields providing an air dose rate of 10^4 rad/hr referenced to 2 MeV E_β maximum either singly or concurrently.

VI.B. CRITERIA FOR METEOROLOGICAL SYSTEMS

VI.B.1. General Criteria for Meteorological Systems

1. A meteorological profile tower shall be located near the reactor facility for determining diffusion and transport of a plume.
2. Transport towers in the region outside of a facility boundary to permit determination of longer range plume trajectories shall be installed when characteristics dictate the need.
3. Tower location shall be representative of surrounding terrain and vegetation cover and shall be outside the influence of anomolous terrain or building effects. (Section IV.B.5 should be consulted for more detail on tower location.)
4. Meteorological instrumentation:
    - shall be located at a minimum of two tower diameters from outside of tower, and
    - shall be placed on the prevailing windward side of tower.
5. Instruments shall be operable within the measurement accuracy prescribed over the normal range of environmental conditions common to the region as indicated by long-term climatological records.
6. At sites where it is impractical to meet the specifications during extreme conditions, provisions shall be made to ensure measurements of wind speed, direction, and direction variability at at least one point during these extreme conditions.
7. Data:
    - recording, processing and display equipment errors either

shall be included in data accuracy limits specified or shall be very small when compared to specified limits of the instrumentation,

- readout capability shall be provided in the control room and at least two other physically separate locations, one of which shall be the emergency operations center, and the other at or near the instrument.

8. The entire meteorological system shall be checked at least quarterly and calibrated and maintained when indicated.

9. The mean time to failure shall be two years.

VI.B.2. Criteria for a Meteorological Profile System

The criteria listed below are in addition to those presented in VI.B.1.

1. At 60 meters above the local roughness elements, or at the maximum height of a potential release if greater than 60 meters, measurements shall be made of wind speed, wind direction, lateral wind direction variability (σ_θ), and temperature and measurements should be made of vertical wind direction variability (σ_ϕ or σ_W).

2. At 9 to 15 meters above the local roughness elements, measurements shall be made of wind speed, wind direction, lateral wind direction variability (σ_θ), and temperature. A duplicate set of wind instruments should be installed at the 9 to 15 meter level to provide uneffected data when the main instrument set is in the wake of the tower.

3. At 2 meters above the local roughness elements, measurements shall be made of wind speed, wind direction, lateral wind variability (σ_θ), and temperature.

4. A surface measurement of precipitation suitable for determining precipitation rate during an accident should be made.

5. Accuracy of the meterological measurements shall be as follows with time averages assumed to be over periods ranging from 15 minutes to 1 hour:

   - Average wind speed: ±0.25 miles per hour (mph) or ±2%
   - Average wind direction: ±5 degrees
   - Starting speed for wind speed and direction: ≤2 mph
   - Mean temperature: ±1°F
   - Mean temperature difference between heights: ±0.1°F
   - Lateral wind direction variability (σ_θ): ±20% (e.g., a vane with a natural wave length of ∿15 meters or less and a damping ratio of ∿0.6)
   - Vertical wind direction variability (σ_ϕ or σ_W): ±35% (e.g., a propellor with a distance constant of ∿1.5 meters or less).

6. Errors due to tower influences shall be added to the above to determine total errors. The above accuracy limits shall include sensor processing, and display errors.

VI.B.3. Criteria for a Meteorological Transport System

The criteria listed below are in addition to those presented in VI.B.1.

1. Wind speed and direction data shall be measured at a height of 15 to 30 meters above local roughness elements.

2. In forested locations, the measurement of wind speed below the vegetation canopy should be considered.

3. Accuracy of the meteorological measurements shall be:

   - Average wind speed: ±0.5 mph or ±5%.
   - Average wind direction: ±5 degrees
   - Starting speed for wind direction and speed: ≤2 mph.

VI.C. CRITERIA FOR AMBIENT RADIATION AND CONTAMINATION SURVEY INSTRUMENTS

VI.C.1. Dose Rate and Contamination Survey Instruments

1. The system shall be capable of detecting beta and photon radiation, and separating the contribution from each. To accomplish this, a detector system which can be operated bare or which can be shielded with 1 gm/cm^2 of polyethylene or similar low Z plastic, should be used.

2. The detection ranges shall be as shown:
   a. Photon Exposure Rate: 0.1 mR/hr to 10^4 R/hr.
   b. Beta Dose Rate: 0.1 mrad/hr to 10^4 rad/hr.

   In recognition of the difficulties in design and construction of a single detector and/or instrument with such a breadth or range, two detectors or instruments are permissible, assuming that all the other criteria specified in this section are met, and that a one decade overlap is provided.

3. Photon energy dependence shall be ±15% over the range 30 keV to 3 MeV.

4. Detection capability shall be provided for beta particles with energies greater than 100 keV. The beta energy dependence shall be ±30% over the range 0.1 to 3 MeV.

5. Detectors and associated electronic circuitry, readout and display devices, and power supplies shall be wholly interchangeable.

6. Overall system accuracy shall be ±40% at the 95% confidence level for any level over the entire operating range, with precision of ±10% for any single measurement level.

7. Overall system response (0 to 90% of full reading) time shall be ≤2 seconds after a warm-up time of one minute. This does not preclude the inclusion of variable response time capability. When the radiation field is removed, the instrument shall indicate within 2 seconds not more than 10% of the total reading in the field.

8. Stability shall be evidenced by the ability of the instrument to maintain zeroing, accuracy, and precision for at least 24 hours after initial switching on.

9. For the operating temperature range the temperature coefficient shall be ≤0.5% per °C and it should be ±15% over the entire range.

10. The operating temperature range of the system shall encompass the extremes anticipated. Where the instrumentation may be exposed directly to ambient outside temperatures, the 50 year extreme shall be applied.

11. The instruments shall be splash-proofed. The instrument system shall be unaffected by relative humidities from 5 to 95% over the designated temperature range.

12. When responding to levels in excess of the maximum range, the readout shall remain full upscale.

13. Extracameral response should be undetectable in photon field to 10 R/hr referenced to 1 MeV energy, and to beta fields providing an air dose of 10 rad/hr referenced to 2 MeV.

14. There shall be no deleterious effect to the instrument from radiofrequency and microwave exposure to 10 mW/cm^2, photon exposure to 5×10^5 R, referenced to the energy range between 0.05 - 1.2 MeV, and from electrostatic charges with potentials to 10,000 volts.

15. The system shall be unaffected by magnetic fields with intensity to 10 oersteds.

16. With the exception of the detector and display, solid state electronics should be used throughout.

17. The instrument shall be designed to be powered by D cells or 9 volt transistor batteries meeting the specifications published by the U.S. National Bureau of Standards.(74) Compatibility with alkaline, Ni Cd, or mercury cells should be considered. Provision for operation from a standard automobile 12 volt system and 117 volt, 60 Hz, alternating current also should be considered.

18. Minimum battery lifetime shall be 200 hours of continuous duty operation at an exposure level of 10% the maximum full scale reading, at temperatures above 0°C. At temperatures below 0°C, alkaline batteries shall be used and the minimum battery lifetime shall be 100 hours of continuous operation.

19. Geotropism, or change in reading with special orientation, shall be ≤2% of full scale reading.

20. Response to noise and vibration shall be undetectable at sound pressure levels ≤100 db, and vibration frequencies of 10 to 100 Hz, with a total excursion of 0.5 mm.

21. Sensitivity shall be ≤5% of mid-scale or decade, where sensitivity is defined as the minimum detectable change in response.

22. Angular dependence shall be ≤±15% in a 2 π steradian frontal direction, referenced to photons with energies in the region 1 ± 0.2 MeV.

23. The instrument shall be equipped with a battery check switch and indicator of battery condition. Low or dead battery indication shall be positive - i.e., the instrument shall read upscale, and zeroing shall be rendered impossible.

24. Readout shall be direct and in units of dose or exposure per hour. However, high range instruments intended exclusively for rescue work may be calibrated in units of R/min or rad/min, and if so, the instrument and readout should be clearly and distinctively marked. The readout shall be such that multipliers (e.g., X10, X100) shall be included.

25. The readout shall be lighted to permit use in darkness; self-illumination should be considered.

26. The instruments, whether used routinely or not, shall be checked for operation on a quarterly basis, and recalibrated and repaired as indicated. In no case shall more than 18 months elapse between calibrations.

27. Overall instrument response shall not change by more than ±10% from the previous calibration when batteries are changed.

28. A 10 mV or mA recorder output shall be provided for instruments which are to be used with a recorder.

29. The total weight of the fully assembled survey meter, including batteries, should not exceed 3 kg (6.6 lbs).

30. If the survey instrument is to be operated while carried (portable) the following shall apply:

    - The instrument is capable of and designed for, convenient transportability by a single person. This criterion does not preclude the use of back packs, neck or shoulder straps, belts, or other means of attachment to the body

    - The weight of the total instrument, including power source, does not exceed 22.5 kg (50 lbs).

31. If the survey instrument is to be operated while mounted in an airplane, motor vehicle or boat (mobile) the following shall apply:

    - Any of the instrumentation that may be used in an airplane shall be designed to operate properly at an altitude of 5000 feet over the surrounding terrain.

    - Mobile instrumentation shall be designed to provide a readout using a strip chart recorder.

    - Each separate protion of the mobile instrument system shall weight less than 50 pounds.

32. If an integrating capability is provided the following shall apply:

    - Portable radiological instruments with integrating capability should have integrating ranges as shown:
      a. Photon Exposure 0.1 to 10^3 R
      b. Beta Dose 0.1 to 10^3 rad

- Integrating units shall be equipped with an audible alarm having a continuous or intermittent warbling tone with a frequency in the region 2 to 7 kHz and a sound level of 85 dbA at a distance of 50 cm from the instrument.
- The alarm shall be presettable to any level by an external switch. External reset capability shall also be provided.
- An alarm test position or switch shall be provided.

VI.C.2. Portable Air Samplers

1. The sampler shall be designed for use with the portable survey meter described in VI.C.
2. To simplify calibration, operation, and interpretation, a fixed sampling rate of 10-30 liters per minute should be used. Sampling rate shall remain constant to within ±25% during normal operation.
3. The unit shall be compatible with standard glass fiber, cellulose fiber, and charcoal loaded filters commonly used for air sampling. The size of the filter used is dependent upon the size of the detector, but a 47 mm diameter should be considered. Filter diameter should not exceed 100 mm.
4. The filter material used shall have an efficiency of 99.5% for particles 0.3 μm in diameter.
5. Power should be provided by wet cells, and these shall conform to the specifications put forth by the National Bureau of Standards.[74]
6. Battery lifetime shall be greater than eight hours under load.
7. The sampling unit shall be provided with a battery test or other indicator of battery condition.
8. Air flow shall be continuously indicated by an appropriate clearly marked gage having an accuracy of ±20%.

VI.C.3. Direct Reading Dosimeters

1. The pocket ion chamber shall have a range of 0 to 200 R if it is to be used for personnel involved in rescue work in which exposures to 100 R may be incurred.[71] If used for other purposes, such as protection of property, the range shall be appropriate to the maximum permitted exposure. The maximum permitted exposure shall be in the range of 40 to 70% of full scale of the pocket ionization chamber used.

2. The instrument shall be provided with an optical system to permit direct readout. Major scale divisions shall be indicated by heavy lines at 0, 50, and 100% of scale; the scale should be further subdivided into tenths and twentieths by progressively shorter and/or less bold lines.

3. Leakage shall be ≤2% of full scale in a 24 hour period.

4. Accuracy shall be ±25% of the true exposure at the 95% confidence level, referenced to 20 to 80% of full scale exposure. Precision at any level shall be ±10%.

5. Energy dependence shall be ±20% for photons in the energy range 35 keV to 2 MeV.

6. The instrument system shall be unaffected by relative humidities from 5% to 95%, over the designated temperature range.

7. For the operating temperature range the temperature coefficient shall be ±0.5% per °C and it should be ±15% over the entire range.

8. The unit shall be rate indpendent to 10^6 R/sec.

9. There shall be no deleterious effect to the dosimeter from radiofrequency and microwave exposure to 10 mW/cm^2, photon exposure to 5×10^5 R referenced to the energy range between 0.05 - 1.2 MeV, and from electrostatic charges with potentials to 10,000 volts.

10. The unit shall be unaffected by magnetic fields with intensities of 10 oersteds.

11. The unit shall be able to withstand mechanical stress or shock equivalent to a drop from a height of three feet onto a hard surface and such a shock or stress shall not change or alter any reading more than ±10% of full scale.

12. Change in reading with spatial orientation shall be ≤2% of full scale.

13. Angular dependence shall be ≤15% over the energy range 35 keV to 2 MeV.

14. Sensitivity shall be ≤5% of midscale.

15. The unit shall (1) be nonresponsive to beta radiations with energies ≤2 MeV, or (2) shall be accurate to within ±30 for beta radiations with energies from 100 keV to 2 MeV. If the latter is selected, the scale shall be calibrated in rads, and for photons 1 R can be taken to equal 1 rad.

VI.C.4. Personal Alarm Dosimeters

1. The criteria established for the integrating survey meters in Section VI.C.1. shall apply.

2. The personal alarm dosimeter shall have a range from 0 to 200 R.

3. A meter, digital register or other readout shall continually register the accumulated dose.

4. The instrument shall weigh no more than 425 grams (8 oz).

5. The instrument should be powered by any single or combination of commercially available alkaline type dry cells. Mercury cells, while acceptable, are discouraged.

VII. AREAS FOR FUTURE STUDY

VII.A. MEASUREMENT SYSTEM STUDY

This study has attempted to provide a method by which airborne material accidentally released from a reactor can be quickly detected and quantified, as well as general criteria for required instrumentation. The method for initial radiological assessment of the release rate needs experimental studies before Phase II is completed. A preliminary test is to be conducted at Hanford within the next few months to experimentally verify the practicality of the method. Full-scale experiments to determine the influence of structures upon diffusion and transport need to be conducted, however, before this technique can be wholly verified. Very little data from such full-scale experiments appears to be available at the present time.

A systems analysis study of accidental releases from reactors should be initiated to help investigators pinpoint those parameters requiring better definition. A systems analysis of the proposed emergency preparedness system would demonstrate the accumulative effect on the predicted consequences of the uncertainties in source inventory, release fractions, release rates, diffusion parameters and trajectory predictions.

VII.B. INSTRUMENT TESTING AND CERTIFICATION LABORATORY

The performance criteria described in this document for emergency instrumentation include severe environmental, mechanical, electrical and radiological requirements. Appropriate evaluation could be performed by the customer or vendor of such equipment or by a third party. Since test equipment to perform the needed evaluation will be quite expensive, few if any of the customers or vendors will possess the entire capability. Consideration should be given to the establishment of a certification-type laboratory to examine and describe both favorable and unfavorable performance parameters of commercially available emergency instrumentation. This laboratory could also provide judgment on special purpose or single items manufactured for any given installation.

The installed and continued performance of emergency instrumentation is another important factor in meeting the emergency instrumentation preparedness criteria. In-place testing of this instrumentation on an established frequency would seem an appropriate requirement to provide proof of performance. The development of such testing programs and schedules could be performed by this certification-type laboratory for adoption by a regulatory agency or satellite testing laboratories.

VII.C. IMPROVEMENT OF METEOROLOGICAL CAPABILITIES

Various remote sensing techniques are presently under development for application to meteorological and air pollution measurements. Because of the cost of establishing and maintaining instrumented tower systems, and their limited extent of vertical penetration into the atmosphere, it would be desirable to conduct a comprehensive survey of such devices to determine their applicability to the emergency preparedness problem. Applicable devices should be investigated in more detail to determine their technical and cost benefits.

A major unsatisfied requirement for the implementation of an emergency preparedness instrumentation system is the existence of a diffusion model which is tested for a variety of terrain and meteorological situations out to distances of 30 to 50 miles and for releases at elevations as great as the taller stacks in existence. No <u>single</u> existing diffusion prediction scheme appears to have been tested against these criteria, nor does it account for processes such as shear and deposition with much accuracy especially at greater distances. Complete satisfaction of this requirement would require diffusion experiments to generate the necessary data. At the present rate this will likely require several years. Some immediate improvement of the diffusion models, however, could be accomplished by a comprehensive analysis of all previous experiments, which led to the existing models, and more recent results and techniques. Diffusion experiments and analyses are presently being supported by the AEC. An accelerated effort, however, might reasonably satisfy the model requirement in a minimum of one to two years.

Another area requiring investigation is mesoscale transport. A better knowledge of the effects of terrain features on mesoscale flow patterns would permit the formulation of numerical models to be used for real-time transport analysis and as an aid in specifying the spatial distribution of wind and radiological stations necessary at specific sites. The development of such a capability will require models for rural and urban areas and fairly extensive data networks to provide the data for testing these models. Some research of this nature is being conducted, however, the research may not provide the necessary data for model verification.

The recent development and successful utilization of sophisticated wind turbulence measuring devices, such as the sonic anemometer, now provides the opportunity to fully describe and parameterize the errors of the less sophisticated wind devices proposed for the emergency preparedness system. This can now be done on an observational basis rather than a theoretical basis as has been done in the past. By such a comparative analysis it would be possible to account for much of the instrumental error inherent in the data from which existing models have been formulated and permit a better comparison of past and recent diffusion results obtained with dissimilar instruments.

A systems analysis of the total prediction problem, however, may point out that research in one area is of much greater value than another. It is possible, of course, that the uncertainty in the final answer is small enough that no further study is required in any of the areas.

VII.D. CORRELATION OF METEOROLOGICAL AND RADIOLOGICAL ACCURACY REQUIREMENTS WITH EMERGENCY PLANS

Governmental emergency plans for coping with emergencies that impact on personnel living in the environs, including emergency action levels, should be developed and correlated with existing meteorological studies and data and the accuracy criteria contained in this document. The extent to which accuracy is sought in describing the air dose distribution and radionuclide concentration over a given area downwind of a nuclear facility following an accident should be balanced with the requirement stated in emergency plans.

The accuracy criteria for meteorological instrumentation and for radiological instrumentation developed in this study is based on assumptions of the potential release to the containment vessel. No emergency plans together with emergency action levels were available to permit development of instrumentation accuracy criteria based on the accuracy required in predicted or measured environmental dose and contamination levels.

Existing dispersion data with concurrent meteorological data has been obtained from previous experiments performed in various parts of the country over different types of terrain and climatological regimes. If action levels were available, accuracy of radiological measurements, dispersion and transport prediction, and the associated meteorological instrumentation could be correlated with this data. This could lead to the conclusion that the instrumentation requirements presented here are too sophisticated or alternatively not sophisticated enough.

VII.E. IMPROVEMENT OF SAMPLING TECHNOLOGY

Power reactors are being designed with no stack as such. Gases are vented near the highest point in the structures. The actual design of many reactors should be studied to determine the best sampling position for the emergency case. We almost always visualize a tall stack to be sampled. The research would review in detail the gaseous waste monitoring systems including those to safeguard the plant in emergencies, identify common approaches, and determine what the optimum position and configuration of the sampler should be.

Losses in sampling lines should be studied with aerosols representative of those in containment structures following an accident. The importance of condensing steam and the development of means for obtaining a truly representative sample in a condensing steam system should be investigated.

Collectors for iodine and noble gases which provide quantitative measurements should be investigated. Much is known about charcoal for iodine collection,[96-115] but when noble gases are present in such large amounts relative to iodine, the collection of the noble gases would seriously interfere with iodine measurements. Studies on specific absorbents for iodine without interference from noble gases should be undertaken. Such things as silver treated zeolites, liquid scrubbers, and others should be explored.

Optimum methods for sampling liquids in a reactor accident should be developed. Details of the reactor liquid systems should be factored into the sampling and analytical scheme. Response of various detector systems for *in situ* and for withdrawn samples should be studied.

VIII. ACKNOWLEDGEMENT

The effort of Lois Peter in preparing the report is greatly appreciated.

REFERENCES

1. Selby, J. M. and C. M. Unruh, "Technological Considerations in Emergency Instrumentation Preparedness. Phase I - Current Capabilities Study", BNWL-1552 (1971).

2. Bell, M. H., "Preparedness for Radiation Accidents: The Role of the Operator and the Influences of Modern Design", in Environmental Contamination by Radioactive Materials, Proceedings of a Joint UN, IAEA and WHO Seminar, Vienna, 24-28 March 1969, IAEA Publication STI/PUB/226 (1969), pp. 571-580.

3. Gumprecht, R. O. "Computer Code RIBD, DUN-SA-94 (1969).

4. DiNunno, J. J., F. D. Anderson, R. E. Baker and R. L. Waterfield, "Calculation of Distance Factors for Power and Test Reactor Sites", TID-14844 (1962).

5. "Operational Accidents and Radiation Exposure Experience Within the United States Atomic Energy Commission, 1943-1967", TID-25128 (1968).

6. Stratton, W. R., "A Review of Criticality Accidents", Prog. Nucl. En. Series IV, Vol. 3, Pergamon Press, New York (1960).

7. Thompson, T. J., Accidents and Destructive Tests", Chapter 11 in The Technology of Nuclear Reactor Safety, Vol. I, MIT Press, Cambridge (1964).

8. USAEC Division of Operational Safety, "Abnormal Reactor Operating Experience", ORNL-NSIC-17 (August, 1966).

9. Barton, C. J., Compiler, International Symposium on Fission Product Release and Transport under Accident Conditions, 2 vols., CONF-650407 (1965).

10. Browning, Jr., W. E., R. P. Shields, C. E. Miller, Jr. and D. F. Roberts, Release of Fission Products on In-pile Melting or Burning of Reactor Fuels, Nuclear Safety Programme Semi-Annual Progress Report for Period Ending June 30, 1963, ORNL-3483, p. 22.

11. Bunch, D. F. and W. P. Gammill, "Radiological Aspects of a Reactor Destructive Test", Proc. First Int. Cong. Radiation Prot. (W. S. Snyder, et.al., eds.), Pergamon Press, Oxford (1968), pp. 589-600.

12. Chamberlain, A. C., et. al., "Behavior of Iodine Vapour in Air", Disc. Faraday Soc. 30:162(1960).

13. Cordes, O. L. "Comparison of Fission Product Releases from the Destructive Tests of Two SNAP 10A/2 Reactors", Proc. First Int. Cong. Radiation Prot. (W. S. Snyder et. al., Eds.), Pergamon Press, Oxford (1968), pp. 571-587.

14. Creek, G. E., W. J. Martin, and G. W. Parker, Experiments on the Release of Fission Products from Molten Reactor Fuels, ORNL-2616 (July 1959).

15. Croft, J. F., R. Iles, and R. E. Davis, "Experiments on the Surface Deposition of Airborne Iodine of High Concentration," AEEW-R-265 (1963).

16. Davies, R. J., "Estimation of Aerosol Concentration in a Nuclear Reactor Containment After an Accident," Proc. Int. Cong. Diffusion Fission Prod., Saclay, France, Nov. 4-6 (1969) (in press).

17. Forsberg, S., T. Westermark and C. E. Holmquist, Sorption of Fission Product Iodine from Air on Different Materials with Application to Nuclear Reactor Accidents, Nukleonik 3 (1), 31 (1961).

18. Freeby, W. A., L. T. Lakey and D. E. Black, "Fission Product Behavior Under Simulated Loss-of-Coolant Accident Conditions in the Contamination--Decontamination Experiment", IN-1172 (1969).

19. Hilliard, R. K., "Fission Produce Release from Uranium Heated in Air", HW-60689 (1959).

20. Hilliard, R. K., L. F. Coleman and J. D. McCormack, "Comparisons of the Containment Behavior of a Simulant with Fission Products Released from Irradiated UO_2", BNWL-581 (1968).

21. Hilliard, R. K. and L. F. Coleman, "Natural Transport Effects on Fission Product Behavior in the Containment Systems Experiment", BNWL-1457 (1970).

22. Horan, J. R. and W. P. Gammill, "The Health Physics Aspects of the SL-1 Accident", Health Phys. 9:177 (1963).

23. Keilholtz, G. W. and C. J. Barton, "Behavior of Iodine in Reactor Containment Systems" ORNL NSIC-4 (1965).

24. Megaw, W. J. and F. G. May, "The Behavior of Iodine Released in Reactor Containers", S. Nucl. Engr. Parts A/B 16:447 (1962).

25. Mishima, J. and L. C. Schwendiman, "Some Observations on Noble Gas Partitioning in Dynamic Air-Water Systems", in Proc. Eleventh AEC Air Cleaning Conf., Richland, 31 August - 3 September 1970, CONF-700816 (1970) pp. 224-237.

26. Miskel, J. A., "Characteristics of the Radioactivity Produced by Nuclear Explosives", UCRL-7761 (1961).

27. Nebeker, R. L., et. al. "Containment Behavior of Volatile Fission Products in the CDE Under Simulated LOFT Conditions", IN-1394 (1970).

28. Rodgers, S. J. and G. E. Kennedy, Fission Product Release during a Simulated Melt-down of a PWR Type Core, Technical Report 63, MSA Research Corporation (1958).

29. Walker, D. H. and G. W. Parker, "Fission Product Behavior Experimental Program", IN-1381 (1970).

30. Engel, R. L., "ISOHLD - A Computer Code for General Purpose Shielding Analysis", BNWL-236 (1966).

31. Mansius, C. A., "A Revised Photon Probability Library for Use with ISOHLD-III", BNWL-236, Suppl. 2 (1969).

32. Argonne National Laboratory, "Reactor Physics Constants", ANL-5800, 2nd Ed. (1963).

33. Lederer, C. M., J. M. Hollander, and IL Perlman, Table of Isotopes, John Wiley and Sons, New York (1967).

34. Allen, Robert E. "Radiation Surveillance Networks", WASH-1148 (1969).

35. Wilson, R. H. "A Method for Immediate Detection of High Level Neutron Exposure by Measurement of Sodium-24 in Humans", HW-73891 (1962).

36. Kiefor, H. and R. Maushart. "Measurement in Successive Stages of an Emergency: Equipment, Methods and Facilities," Protection of the Public in the Event of Radiation Accidents, Proc. WHO Seminar, Geneva, 18-22 November 1963, World Health Organization, Geneva (Pub. 1965), pp. 157-169.

37. Henderson, R. W. "Source Measurement: Determining the Release from a Point Source by Remotely Located Samplers", LA-3094 (1963).

38. King. W. C. "Radiological Health Aspects of Underground Nuclear Testing", UCRL-70608 (1970).

38A. King, W. C. "An Instrument to Determine Radioactive Clouds and Its Application in Monitoring Underground Nuclear Tests at the Nevada Test Site", UCRL-14633 (1966).

39. Palmer, G. H., T. F. Johns, K. E. G. Percy. "Rapid Detection of an Accidental Discharge of Radioactive Material to the Atmosphere," in RAPID Method for Measuring Radioactivity in the Environment, Proc. Symp. Neuherberg, 5-9 July 1971 (Pub. 1971), pp. 737-744.

40. Watson, E. C. and D. L. Strenge. "Some Characteristics of Potential Radioactive Releases to the Atmosphere Following Hypothetical Reactor Accidents", BNWL-1580.

41. Slade, D. N. "Meteorology and Atomic Energy", TID-24190 (July 1968).

42. Hay, J. S., and F. Pasquil. "Diffusion from a Continuous Source in Relation to the Spectrum and Scale of Turbulence". Advances in Geophysics, Vol. 6, pp. 345-365, F. N. Frenkiel and P. A. Sheppard (eds), Academic Press Inc., New York (1959).

43. Sutton, O. G. "A Theory of Eddy Diffusion in the Atmosphere", Proc. Royal Soc. (London), Series A, 135:143 (1932).

44. Pasquill, F. Atmospheric Diffusion, D. Van Nostrand Company, Ltd., London (1962).

45. Pasquill, F., and F. B. Smith. "The Physical and Meteorological Basis for the Estimation of the Dispersion". Presentation at Second International Clean Air Congress of the International Union of Air Pollution Prevention Assoc., Dec. 6-11, 1970. Washington D. C. (1970).

46. Smith, F. B., and J. S. Hay. "The Expansion of Clusters of Particles in the Atmosphere", Quart. J. Roy. Meteorol. Soc. 87:82 (1961).

47. Cramer, H. E., et. al., "Meteorological Prediction Techniques and Data System", Report GCA-64-3-G (1964).

48. MOAA Technical Memorandum, "Atmospheric Transport and Diffusion in the Planetary Boundary Layer, January-July 1970". Air Resources Laboratories Semiannual Research Program Review for the Division of Reactor Development and Technology, USAEC, ERLTM-ARL-28, 47 pp. NOAA Air Resources Laboratories, Silver Spring, Maryland (1970).

49. Gifford, F. A., Jr., "Atmospheric Dispersion Calculations Using the Generalized Graussian Plume Model," Nuclear Safety, Vol. 2, No. 2 (1960).

50. Cramer, H. E. "A Practical Method for Estimating the Dispersal of Atmospheric Contaminants", Proceedings of the First National Conference on Applied Meteorology, pp. C-33 to C-55, American Meteorological Society, Hartford, Conn. (October 1957).

51. Cramer, H. E. "A Brief Survey of the Meteorological Aspects of Atmospheric Pollution", BAM 40:165 (1959).

52. Cramer, H. E. "Engineering Estimates of Atmospheric Dispersal Capacity". J. Am. Ind. Hyg. Assoc. 20:183 (1959).

53. Jones, J. I. P., and F. Pasquill. "An Experimental System for Directly Recording the Statistics of the Intensity of Atmospheric Turbulence, Quart. J. Roy. Meteorol. Soc. 85:225 (1959).

54. Brock, F. V., and D. J. Provine. "A Standard Deviation Computer", J.A.M. 1:81 (1962).

55. Gill, G. C., and E. W. Bierly. "A Meteorologically Operated Stack Control System". J.A.M. 2:431 (1962).

56. Gill, G. C., L. E. Olsson, and Motozo Suda. "Errors in Measurements of Wind Speed and Direction Made with Tower or Stack-Mounted Instruments", Publication 06973-1-P, Department of Meteorology and Oceanography, College of Engineering, University of Michigan, Ann Arbor, Michigan (1966).

57. "Guide to Sampling Airborne Radioactive Materials in Nuclear Facilities", American National Standard N13.1 (1969). Cf. also Postma, A. K. and L. C. Schwendiman, "Particle Deposition in 90° Tube Bends", HW 81746 (1964).

58. Sehmel, G. A., "Particle Sampling Bias Introduced by Anisokinetic Sampling and Deposition Within the Sampling Line", Am. Ind. Hyg. Assn. J. 31:758 (1970).

59. Kathren, R. L. "Activity and Thyroid Dose from Radioiodines" Nucleonics 22(11):60 (1964).

60. Rockwell, T., III., Reactor Shielding Design Manual, Van Nostrand, Princeton, New Jersey pp. 345-425. (1956).

61. Woodward, William J. "An Improved Air Monitor in a Standard Nuclear Instrument Module," DP-1260 (1971).

62. Bisby, H. "Radiometric Techniques and Instrumentation for In-Line Process Monitoring", in Prog. Nucl. En., Ser IV Technology, Engineering, and Safety, Vol 5, C. M. Nicholls, Ed., Pergamon Press (1963), pp. 251-282.

63. Riel, G. K. and D. Duffey. "Underwater Gamma Ray Spectrometers for Monitoring Environmental Water at Nuclear Power Stations," IEEE Trans. Nucl. Sci. NS-14:275 (1968).

64. Ragupathy, S. and K. G. Vohra. "A Multichannel Analysis System for Low Levels of Fission Products in Reactor Coolants", Nucl. Electronics, Proc. Conf. Bombay, 22-26 November, 1965, IAEA (pub. 1966), pp. 333-339.

65. Knezeirch, M., R. L. Kathren, O. K. Helferich, and K. R. Kase, "Loss-of-Water Experiment at the Livermore Pool-Type Reactor, Health Phys. 11:481 (1965).

66. Hubbell, J. H. "Photon Cross-Sections, Attenuation Coefficients, and Energy Absorption Coefficients from 10 keV to 100 GeV", NSRDS-NBS 29 (1969).

67. Costrell, L. "Standard Nuclear Instrument Modules", TID-20893, (Rev. 2) (Jan. 1968); also (Rev. 3) (1969).

68. Zuerner, L. V. and R. L. Kathren. "Evaluation Program for Portable Radiation Monitoring Instruments", BNWL-SA-1947 (1968); cf. also Health Physics Operational Monitoring, C. A. Willis and J. Handloser, Eds., Vol. 2. Gordon and Breach, New York (1971).

69. Unruh, C.M. "Methods of Measurement and Interpretation of Results in Radiation Monitoring and Dosimetry", in Radiation Protection Monitoring, Proc. Symp. Bombay, 9-13 December 1968 (Pub 1969), pp. 123-147.

60. "Exposure to Radiation in an Emergency," National Committee on Radiation Protection and Measurements Report No. 29, University of Chicago (1962).

71. Vallario, E. J. and R. J. Catlin. "Emergency Dose Criteria for Recovery of Personnel and Facilities," in Radiation Accidents and Emergencies in Medicine, Research, and Industry, L. L. Lanzl, J. H. Pingel, and J. H. Rust, Eds., Charles C. Thomas, Springfield (1965), pp. 217-222.

72. Fish, H. R., Jr. "Dosimetry and Instruments for Accident Situation Assessment", in Radiation Accidents and Emergencies in Medicine, Research, and Industry, L. L. Lanzl, J. H. Pingel, J. H. Rust, Eds., Charles C. Thomas, Springfield (1965), pp. 207-215.

73. Keene, A. R. et. al. "Elements of Emergency Planning for Coping with a Serious Accident", Health Physics 9:793 (1963).

74. "Specifications for Dry Cells and Batteries", National Bureau of Standards Handbook 71, U.S. Government Printing Office, Washington (1962).

75. "Environmental Monitoring in Emergency Situations," IAEA Safety Series No. 18, IAEA, Vienna (1966).

76. Howells, H. and H. J. Dunster. "Environmental Monitoring in Emergencies", Environmental Surveillance in the Vicinity of Nuclear Facilities, Proc. Symp, Charles C. Thomas, Springfield IL (1970), pp. 151-161.

77. Tait, G. W. C. and W. F. Merritt. "Emergency Radiation Monitoring of Drinking Water", Health Phys. 1:164 (1958).

78. Brodsky, A. and G. V. Beard (Eds.), "A Compendium of Information for Use in Controlling Radiation Emergencies", TID-8206 (1960).

79. Block, S. and E. L. Beard. "Converting a Portable Survey Meter's Ion Chamber into a Continuous Air Monitor by a Simple Expedient" in Hazards Control Quarterly Report No. 22, UCRL-14534 (July-September 1965), pp. 32-40.

80. Block, S., E. Beard, and O. Barlow. "A Portable Continuous Air Monitor for Field or Laboratory Use" in Hazards Control Progress Report No. 21, UCRL-14351 (April-June 1965) pp. 1-9.

81. Cohen, J. J. and R. D. Taylor. "Development of a Lightweight Portable "Hi-Vol" Air Sampler", in Hazards Control Progress Report No. 28, UCRL-50007-67-2 (May-August, 1967), pp. 19-20.

82. Stoddard, D. H. "Emergency Air Sampler", Health Phys. 11:320 (1965).

83. Bloor, W. A., R. E. Eardley, and A. Dinsdale, "A Gravimetric Personal Dust Sampler" Ann. Occup. Hygiene 11:81 (1968).

84. Higgins, R. I. and P. Dewell. "A Gravimetric Size-Selecting Personal Dust Sampler" in Inhaled Particles and Vapours, C. N. Davies, Ed., Vol. 2, Pergamon Press, Oxford (1967). pp. 575-583.

85. Ingram, W. T. "Personal Air-Pollution Monitoring Devices", Am. Ind. Hyg. Assn. J. 25:298 (1964).

86. Lindekin, C. L. and R. D. Taylor. "Battery-Operated Staplex Sampler", Am. Ind. Hyg. Assn. J. 26:322 (1965).

87. Sherwood, R. J. and D. M. S. Greenhalgh. "A Personal Air Sampler," Ann. Occup. Hyg. 2:127 (1960).

88. Block, S., E. L. Beard, and A. H. Forsman. "A Personal Air Sampler for Atmospheric Contamination", UCRL-6192 (1961).

89. Allendew, D. and Collip, I. W. "A Personal - Radiation Monitor with Audible Warning Device," J. Sci. Inst. 33:120 (1965).

90. Brown, D. P. "A Pocket-Size, Signaling, Radiation Dosimeter", Health Physics 12:943 (1966).

91. Erickson, G. L. "A Selectable Level Pocket Dose Rate Alarm Dosimeter", DUN-5938 (1969); cf. also "New Rate and Integrating Personal Alarm Dosimeter Designs, DUN-SA-130 (1970).

92. Jones, A. R. "A Miniature Warning Dosimeter", Health Physics 11:363 (1967).

93. Lakin, R. "A Personnel Radiation Dosimeter with Storage for Preset Alarm and Continuous Readout", UCRL-14925-T (October 17, 1965); Presented before 13th Annual Nuclear Science Symposium, Boston. cf. also UCRL-14534 (1965) pp. 28-31.

94. Tanaka, E. "A Personal Radiation Alarm Dosimeter", Health Physics 13:1337 (1967).

95. American National Standards Institute. "Interrelationship of Quartz Fiber Electrometer Type Dosimeters and Companion Dosimeter Chargers," ANSI Standard N3.2-1965 (1965).

96. Mishima, J. and L. C. Schwendiman, "Laboratory and Field Study of an Environmental Charcoal Iodine Sampler," BNWL-CC-2262. (1969)

97. Keller, J. H., F. A. Duce and W. J. Maeck, "A Selective Adsorbent Sampling System for Differentiating Airborne Iodine Species," in Proc. Eleventh AEC Air Cleaning Conf., Richland, 31 August - 3 September 1970, CONF-700816 (1970) pp. 621-634.

98. Jones, L. R., "Effect of Gamma Radiation on Adsorption of Iodine and Methyl Iodide on Activated Carbon," in Proc. Eleventh AEC Air Cleaning Conf., Richland, 31 August - 3 September 1970, CONF-700816 (1970) pp. 526-538.

99. Evans, A. G. and L. R. Jones, "Iodine Retention Studies," DP 1259 (1971).

100. Evans, A. G., "Effect of Service on Retention of Iodine by Activated Carbon," in Proc. Eleventh AEC Air Cleaning Conf., Richland, 31 August - 3 September 1970, CONF-700816 (1970) pp. 539-550.

101. Schindler, R. E., R. R. Hammer, D. E. Black and L. T. Lakey, "Development of a Continuous Sampler-Monitor for the Loft Containment Atmosphere," in Proc. Eleventh AEC Air Cleaning Conf., Richland, 31 August - 3 September 1970, CONF-700816 (1970) pp. 653-667.

102. Schultz, R. J., "Application of the Continuous Sampler Monitor (CSM) as a Hazard Evaluation Instrument," in Proc. Eleventh AEC Air Cleaning Conf., Richland, 31 August - 3 September 1970, CONF-700816 (1970) pp. 668-679.

103. "Current Practices in the Release and Monitoring of ^{131}I and NRTS, Hanford, Savannah River and ORNL," ORNL-NSIC-3 (1964).

104. Hawes, J. E. Jr., R. T. Ritzman, D. L. Morrison and C. W. Townby, "Investigation of Techniques for Sampling and Analysis of Iodine Under Simulated Accident Conditions," BMI-1814 (1967).

105. Keller, J. H., F. D. Duce and F. O. Caston, "Retention of Iodine on Selected Particulate Filters and a Porous Silver Membrane Being Considered for the LOFT Maypack," IN-1078 (1967).

106. McConnon, D., "Radioactive Sampling with Activated Charcoal Cartridges," HW-77126 (1963).

107. Davis, R. J., "Removal of Radioactive Particles with Fibrous Filters," ORNL-4524 (1970).

108. Adams, R. E., "Removal of Radioiodine from Flowing Humid Air by Iodized Charcoals," ORNL-TM-2040 (1967).

109. Cottrell, Wm. B., "Removal of Iodine by Solid Sorbents," Sec. 2.1, ORNL-TM-2230 (1968).

110. Ludwick, J. D., "The Iodine Collection Efficiency of Activated Charcoal from Hanford Reactor Confinement Systems," in Nuclear Applications and Technology, Vol. 8, p. 310 (1970).

111. Mecca, J. E. and J. D. Ludwick, "In-Place Testing of Hanford Reactor Charcoal Confinement Filter Systems Using Iodine Tagged with ^{131}I," in Nuclear Applications and Technology, Vol. 9, 1970).

112. Ludwick, J. D., "Radiochemical Standardization of Oxidant Detectors for Iodine," in Analytical Chemistry, Vol. 41, p. 1907 (1969).

113. Haller, W. A. and R. W. Perkins, "Organic ^{131}I Compounds Released from a Nuclear Fuel Chemical Processing Plant, in Health Physics, Vol. 13, p. 733 (1967).

114. Ludwick, J. D., "Investigation of the Nature of ^{131}I in the Atmosphere," HW-81746 (1964).

115. Ludwick, J. D., "The Measurement of ^{131}I Transport in Atmospheric Diffusion Experiments," BNWL-235-2 (1966).

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