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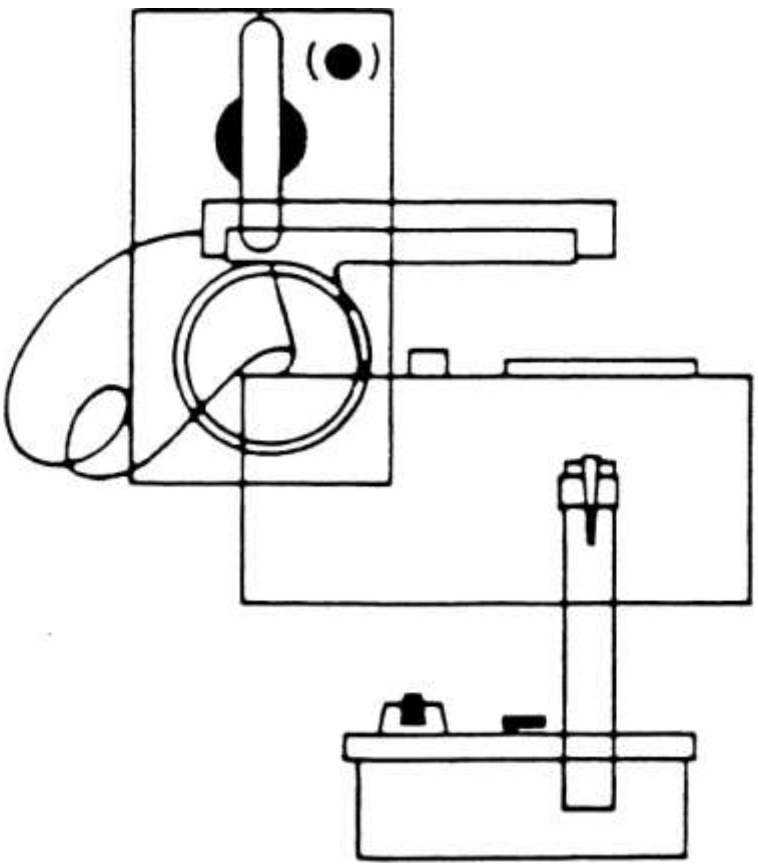
Guidance on Offsite Emergency Radiation Measurement Systems

Phase 1 -Airborne Release



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Guidance on Offsite Emergency Radiation Measurement Systems

Phase 1 - Airborne Release

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For the
Federal Radiological Preparedness Coordinating Committee
Subcommittee on Offsite Emergency
Instrumentation for Nuclear Incidents

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Notice

This document is intended for use by Federal, State, and local officials who are responsible for radiological emergency preparedness. It has been prepared by the Federal Radiological Preparedness Coordinating Committee (FRPCC), Subcommittee on Offsite Emergency Instrumentation. This document is a revision of FEMA REP-2, Rev. 1, dated July 1987. FEMA REP-2, Rev. 2, replaces FEMA REP-2, Rev. 1 which should no longer be used.

FEMA REP-2 was initially published in September 1980 and was reissued as FEMA REP-2, Rev. l/WINCO-1029 in December 1985, by the Idaho National Engineering Laboratory on a preliminary basis as a WINCO technical report/FEMA REP document for interim use and comment. The Federal Register notices of June 18, 1987, Vol. 52, No. 117, page 23210, and September 1, 1987, Vol. 52, No. 169, page 32965, requested additional comments on the July 1987 edition of FEMA REP-2, Rev. 1.

All comments received to date have been considered in the June 1990 publication of FEMA REP-2, Rev. 2. This edition of FEMA REP-2, Rev. 2, is issued for interim use and comment. Comments are encouraged for consideration by the FRPCC Subcommittee prior to FEMA's publishing FEMA REP-2, Rev. 2, in final. All comments should be forwarded to: Rules Docket Clerk, Federal Emergency Management Agency, Room 840, 500 C Street Southwest, Washington, D.C. 20472. Comments will be accepted through December 31, 1990.

Preface

This report provides recommendations on emergency instrumentation necessary to measure airborne releases in the event of a nuclear accident at a nuclear power plant to Federal, State, and local officials responsible for offsite radiological emergency preparedness. It covers the selection and use of radiation measurement systems needed to implement the protective action guidance presented in the EPA Manual of Protective Actions for Nuclear Incidents (January 1990). This document is also based on the material provided in NUREG-0396, EPA520/1-78-016, Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants (December 1978).

This report is limited to recommendations on the use of emergency radiation systems to detect and measure radioactive components in the airborne plume by State and local governments during a nuclear accident. It is assumed that these systems will be augmented during the course of the accident by an extensive Federal emergency response, if necessary or requested.

Other reports in this series which address the instrumentation requirements for measurement of radioactivity in the ingestion pathways are: (1) FEMA REP-12, Guidance on Offsite Emergency Radiation Measurement Systems, Phase 2 - The Milk Pathway (September 1987), and (2) FEMA REP-13, Guidance on Offsite Emergency Radiation Measurement Systems, Phase 3 -Water and Non-Dairy Food Pathway (May 1990). A future report in this series will address radiation instrumentation requirements for recovery and reentry operations.

The function of the measurement systems is to acquire sufficient radiation data to confirm protective action decisions that have been made in time to ensure that radiation exposure to the public will be as low as is reasonably achievable (ALARA). By the same token, it is necessary to consider keeping the cost of the systems within reasonable limits, without compromising ALARA exposure, by utilizing existing instrumentation and resources whenever possible. Therefore, planning for the design and implementation of the system must be thorough to assure a rapid and proper response in the event of an accident at a nuclear power plant.

This report includes many topics which are ancillary to the specific instrumentation requirements of the emergency response organization. Consideration of these topics was necessary to provide a basis for the specific recommendations with respect to accident notification, exposure rate verification, response team manpower, etc. The inclusion of these topics should be of value to State and local agencies involved in the development and establishment of offsite radiological emergency response. The recommendations presented in this report regarding offsite emergency radiation measurement systems are based on radiation instrumentation and methodologies that are currently available.

Abstract

This revision of FEMA REP-2, Guidance on Offsite Emergency Radiation Measurement Systems, Phase 1 - Airborne Releases, was prepared for use by Federal, State, and local officials who are responsible for radiological emergency preparedness. It has been prepared by the Federal Radiological Preparedness Coordinating Committee, Subcommittee on Offsite Emergency Instrumentation. The original FEMA REP-2 document, dated September 1980, has been updated, based on existing regulations and recent evaluations of air sampling and instrumentation systems, and expanded to include guidance on airborne particulate monitoring to provide complete coverage of monitoring an offsite airborne release of radioactivity from a nuclear power plant accident.

Brand name instruments referred to in this document are included only as examples. Reference herein to any specific commercial product, trademark, or manufacturer does not necessarily constitute or imply its endorsement or recommendation of its use. Civil Defense instruments, e.g., CD V-700, CD V-715, etc., are referenced because of their availability for use in the offsite radiological emergency preparedness program in each State.

Instrumentation and equipment requirements for the Plume Exposure Rate Verification System and the Emergency Worker Radiation Exposure Monitoring System were evaluated. Both systems require reliable low-range (0-50 mR/h) and high-range (0-100 R/h) gamma exposure rate instrumentation. The Plume Exposure Rate Verification System also requires simple count rate instrumentation, e.g., pancake type GM detectors, or 1" x 1" or 2" x 2" NaI(Tl) detectors, for counting particulate and gaseous air samples. This system also requires the proper air sampling equipment, e.g., a calibrated, field operable air pump, particulate prefilter, and an adsorber cartridge to selectively collect radioiodine. Silver zeolite and silver alumina appear to be the better adsorber media for this purpose. Particulate air filters are more accurately evaluated under laboratory conditions.

Therefore, it is recommended that both the particulate filter and adsorber cartridges be saved for confirmatory analyses at a laboratory type facility. The Emergency Worker Radiation Exposure Monitoring System also requires both direct reading and indirect reading personal dosimeters. It is recommended that each emergency worker have (1) two direct reading dosimeters, e.g., a 0-5 R or 0-20 R dosimeter in conjunction with a 0-200 R dosimeter, to provide a basis for in-the-field protective action decision making and provide a measurement above the full scale range of the lower range dosimeter in the case of an accidental high exposure and (2) an indirect reading dosimeter, e.g., a thermoluminescent dosimeter, to provide legal documentation of the total exposure accrued during a radiological accident at a nuclear power plant.

Summary

FEMA REP-2, Rev. 2, Guidance On Offsite Emergency Radiation Measurement Systems, Phase I - Airborne Release, updates information on currently existing regulations and recent evaluations of air sampling and instrumentation systems. The document has been expanded to include particulate monitoring to complete the guidance on monitoring an offsite airborne release of radioactivity. It was prepared by the Federal Radiological Preparedness Coordinating Committee, Subcommittee on Offsite Emergency Instrumentation.

Brand name instruments referred to in this document are included only as examples. Reference to any specific commercial product, trademark, or manufacturer does not necessarily constitute or imply an endorsement or recommendation of its use. Civil Defense instruments, e.g., CD V-700, CD V-715, etc., are referenced because of their availability for use in the offsite radiological emergency preparedness program in each State.

This document addresses the basic considerations and assumptions for guidance on offsite emergency instrumentation for monitoring an airborne release. Included is a discussion of protective action decision-making and the use of emergency radiation measurement systems for verification of protective actions. The measurement systems that are recommended in this document are reliable instrumentation and techniques for monitoring radiation exposures from airborne radioactive releases from nuclear power plants.

Two emergency radiation measurement systems are described in detail. These are: 1) the Plume Exposure Rate Verification System and 2) the Emergency Worker Radiation Exposure Monitoring System. The Plume Exposure Rate Verification System is designed to provide offsite measurements to confirm and supplement the data and dose projections provided by the facility in its notification of a nuclear accident to the State and/or local emergency operations centers. The Emergency Worker Radiation Exposure Monitoring System is for measuring the emergency worker's accrued radiation exposure from the plume. An emergency worker is defined as an individual who has an essential mission within the Plume Emergency Planning Zone to protect the health and safety of the public who could be exposed to ionizing radiation from the plume or its deposition.

Protective action decision making for radiological emergencies is based upon Protective Action Guides (PAGs). The PAGs are projected exposure ranges for whole body or thyroid. The PAG are 1 to 5 rem for projected whole body exposure and 5 to 25 rem for projected thyroid exposure. Protective action recommendations may vary, ranging from doing nothing, to sheltering in place, to evacuating affected population groups, or to administering radioprotective drugs, primarily to emergency workers. Usually, protective actions are recommended at the low end of the projected exposure range unless the State or local governments have good reasons for not doing that. The dose projection calculations should utilize conventional atmospheric dispersion modeling techniques and accepted dose conversion factors. The models should readily accept input for changing release rates or meteorological conditions.

The emergency decision maker should base the initial protective action decisions upon information obtained over the facility's emergency notification system. The reason for basing the

initial protective actions on facility information is that protective actions should be implemented before there is an emergency related airborne release of radioactivity from the facility. The first protective action expected to require implementation is avoidance of exposure to the total radioactivity in the plume and to inhalation of the radioiodines in the plume. This action must be implemented without delay in nearby downwind areas. Close in areas may be directed to undertake a precautionary evacuation. Some of the factors which may influence the off site protective action decisions are: 1) the probability of an airborne release occurring, 2) the estimated time at which the release may begin, 3) the radioactive composition of the release, 4) the magnitude of the release, 5) the estimated time for the release to reach the affected offsite population, and 6) the duration of the release. Information concerning all of these factors should be readily available from the facility. If there has been an airborne release of radioactivity from the facility, the emergency decision maker should utilize the Plume Exposure Rate Verification System to determine if the areas covered by the initial protective action decisions are large enough.

The Plume Exposure Rate Verification System should be made up of radiation detection instruments and air sampling equipment which are readily available either from commercial vendors or from State Civil Defense resources. The radiation detection instruments should include high-range (100 R/h) and low-range (50 mR/h) survey meters for exposure rate determinations and a count rate meter for measurements of air sample cartridges and/or filters. The low-range survey meters should have a moveable shield for making open and closed window readings to aid in determining the ground level location of the radioactive plume. The high-range survey instruments should be equivalent to a sealed ion chamber. The reason for this is that unsealed ion chambers may became internally contaminated and the older model CM tube type detectors may saturate and became inoperable at high exposure rates. The count rate instruments may be either GM detectors with a gross count rate meter or NaI(Tl) detectors with single channel or dual channel analyzers.

The air sampling equipment should consist of an air pump with a filter holder designed to hold a particulate filter and an adsorber cartridge. The air pump should be capable of drawing a flow rate of 1 to 5 cubic feet per minute with both the particulate filter and the adsorber cartridge in place with a minimum sample volume of about 10 cubic feet collected. There are three types of inorganic adsorber media cartridges that may be used to selectively collect radioiodine in the presence of noble gases. The inorganic adsorber media are: 1) silver zeolite, 2) silver alumina, and 3) silver silica gel. The silver zeolite adsorber appears to have the best performance characteristics, however, all three adsorber media types will perform adequately if the user is aware of and abides by the environmental and physical operational constraints which may limit each medium’s use. Also, there appears to be variations in radioiodine retention efficiency between different production lots of a given adsorber type. Therefore, it is recommended that the user obtain a test certification from the vendor which specifies the adsorber's performance with respect to changes in relative humidity and to changes in flew rate. These test certificates should be available for each new production run for a given adsorber type.

All of the radiation detection instruments and air sampling equipment used in the Plume Exposure Pate Verification System must be calibrated. The calibration frequency should be based on the recommendations of the manufacturer of the equipment and specified in the operating procedures section of the State or local emergency response plan. However, the interval of time between recalibration and battery replacement must not exceed one year for all radiological instruments used in the radiological emergency preparedness program. The radiation detection instruments and air sampling equipment must meet the requirements of the American National Standards Institute (ANSI). References to the ANSI documents are provided in Appendix E.

The FRPCC Subcommittee considered an offsite fixed detection system which utilized a ring of offsite gamma sensitive detectors, for the initial detection of an airborne release. Such a system cannot guarantee an early warning of a release. It would be very expensive to install and especially expensive to operate. Since this type of monitoring system cannot guarantee the detection of all offsite releases, the use of fixed offsite monitors for emergency response planning purposes for initial detection of an airborne release is not recommended. Measurements of a release can be achieved more rapidly and more accurately by facility sampling. Therefore, the FRPCC Subcommittee recommends that appropriate arrangements be made with the nuclear power facility to provide advanced warnings of anticipated releases and dose projections.

The number of offsite monitoring teams required for the Plume Exposure Rate Verification System will be site specific. Some of the factors which will affect the number of teams are: 1) geographical constraints and 2) general team mobility, e.g., existing road networks. At a minimum, there should be two well trained individuals on each monitoring team and there should be 100 percent replacement personnel to provide adequate resources for 24-hour per day monitoring if necessary. In addition to replacement personnel, there should be resources for approximately a 20 percent replacement of radiation detection instruments and air sampling equipment as a routine precautionary measure to allow for equipment failure.

The primary objectives of the Emergency Worker Radiation Exposure Monitoring System are to minimize the exposure of emergency workers to radiation from the accident and to continuously measure the radiation worker's accrued radiation exposure. Emergency workers include the following: radiation monitoring team personnel; transportation services (evacuation vehicle/bus drivers); law enforcement, fire fighting, and rescue personnel, including ambulance crews; personnel carrying out backup or route alerting procedures; traffic control personnel; emergency operating center personnel; some personnel at institutional, health service, or industrial facilities, and some essential services or utility personnel. These personnel are considered emergency workers only when their services are required to protect the health and safety of the general public during the emergency phase of an accident.

The primary radiation exposures of concern to emergency workers are: 1) whole body external exposure to gamma radiation from airborne particulates, gases, and particulate radioactivity deposited on or near the ground and 2) internal thyroid exposure from inhalation of radioiodines. Therefore, dosimetry for external beta radiation is not required. Three categories of data are needed for emergency worker exposure evaluation. These categories are: 1) projected exposure rate patterns for planning purposes, 2) survey measurements to estimate radiation exposure at specific assigned emergency worker locations within the plume exposure emergency planning zone, and 3) personal dosimetry to measure accrued radiation exposure. The same high-range (100 R/h) and low-range (50 mR/h) radiation survey instruments and air sampling equipment used by the emergency workers on monitoring teams for the Plume Exposure Rate Verification System may be used to provide measurements for verifying projected exposure rate patterns and to provide an estimate of radiation exposure at specific assigned emergency worker locations. However, all emergency workers within the plume exposure emergency planning zone must have both direct reading and indirect reading dosimeters to measure their accumulated radiation exposure. The FRPCC Subcommittee recommends for emergency workers the use of two direct reading dosimeters, a 0-5 R or 0-20 R in conjunction with a 0-200 R. The 0-5 or 0-20 R range will provide a good measurement of the most reasonably expected preplanned exposures in conjunction with a 0-200 R dosimeter for possible accidental exposures that might be received in excess of the range of the 0-5 R dosimeter. The indirect reading dosimeters, e.g., film badges or preferable thermoluminescent dosimeters, should be used to provide a permanent record of the radiation exposure received by the emergency worker during the course of the accident. Both the direct reading and indirect reading dosimeters must meet the ANSI criteria referenced in Appendix E of this document.

Individuals who might come in contact with radioactive materials during the emergency as a result of the accident and whose emergency job assignments are outside the plume EPZ should be considered radiation workers. For example, those personnel responsible for environmental sampling, radiological monitoring and radiological record keeping at emergency worker or evacuee monitoring centers, decontamination centers, traffic and access control points, medical services or hospitals, provided they are located outside the plume EPZ, are considered to be radiation workers. Exposure limits allowed for these individuals should be the same as those allowed for a radiation worker for occupational radiation exposure, i.e., up to five rem for the duration of the emergency. These personnel are also required to have appropriate dosimetry (a permanent record dosimeter and at least one direct reading dosimeter) to monitor an individual's radiation exposure. Dosimetry requirements for all anticipated radiation workers must be specified in the emergency response plans and operating procedures.

Personnel without public health and safety missions, such as farmers for animal care, other agribusinesses, environmental/agricultural sampling team members, essential service personnel, or other members of the public who must reenter a restricted area following plume passage and delineation of the restricted area, should be limited to the occupational radiation worker exposure limit rather than the emergency worker exposure limit. Each individual should be provided a permanent record dosimeter and at least one direct reading dosimeter capable of monitoring the radiation worker's exposure limit up to five rem for the duration of the emergency.

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1 INTRODUCTION

This revision of FEMA REP-2, Guidance on Offsite Emergency Radiation Measurement Systems, Phase 1 - Airborne Releases, was prepared for use by Federal, State, and local officials who are responsible for radiological emergency preparedness. It has been prepared by the interagency Federal Radiological Preparedness Coordinating Committee, Subcommittee on Offsite Emergency Instrumentation for Nuclear Incidents.

Brand name instruments referred to in this document are included only as examples. Reference herein to any specific commercial product, trademark, or manufacturer does not necessarily constitute or imply its endorsement or recommendation of its use. Civil Defense instruments, e.g., CDV-700, CDV-715, etc., are referenced because of their availability for use in the offsite radiological emergency preparedness program in each State.

The purpose of this report is to provide guidance on emergency radiological instrumentation to State and local agencies responsible for measuring radioactive airborne releases in the event of a nuclear accident at a light water nuclear power plant. The guidance presented in this document covers the selection and use of radiation measurement systems based on the protective action guidance as presented in the U. S. Environmental Protection Agency (EPA) "Manual of Protective Actions for Nuclear Incidents" (January 1990).[1] The guidance is also based on the planning provided in NUREG-0396, EPA520/1-78-016 "Planning Basis for the Development of State and Local Government Radiological Emergency Response Plans in Support of Light Water Nuclear Power Plants" (December 1978).[2]

This "Phase 1 - Airborne Release" document addresses the radiation instrumentation and data collection systems that:

1. Acquire gaseous and particulate radiation data for use in confirming the need to implement protective action against direct exposure to an airborne release,
2. Are located off the site of light water nuclear power reactor facilities,
3. Are operated by State and/or local organizations, and
4. Provide radiological data and/or information to an Emergency Operations Center (EOC),[3] or its equivalent as stated in State Plans, for protective action decision-making.

The function of the measurement systems addressed in this document is to acquire sufficient radiation data for use in verifying protective action decisions in time to ensure that radiation exposure to the public will be as low as is reasonably achievable (ALARA). By the same token, it is necessary to consider keeping the cost of the systems within reasonable limits, without compromising AIARA exposure, by utilizing existing instrumentation and resources whenever possible. Therefore, planning for the design and implementation of the system must be thorough to assure a rapid and proper response in the event of a nuclear accident.

Since the first publication of this document, FEMA-REP-2,[4] new regulations have been published, other regulations have been revised, and additional evaluations have been made on offsite emergency response instrumentation and measurement systems. This revision of FEMA-REP-2 is updated based on existing regulations and recent evaluations of air sampling and instrumentation systems. Also, a section has been included on particulate monitoring to complete the guidance on emergency monitoring of an airborne release.

During 1975 a Federal Interagency Task Force on Emergency Instrumentation for Nuclear Incidents at Fixed Facilities was established by the Federal Interagency Central Coordinating Committee for Radiological Emergency Preparedness. This Task Force coordinated the interagency responsibilities described in the Federal Register notice of December 24, 1975.[5] The Task Force recommended emergency instrumentation systems, that are maintained and operated by the Federal, State and/or local organizations for radiation measurements in an emergency at commercial nuclear power reactor sites beyond the site boundary and not with those emergency instrumentation systems maintained and operated by the reactor licensee.

In 1980, the Federal Emergency Management Agency (FEMA) published its regulation, 44 CFR 351 (45 FR 69904, 10/22/80),[6] which established Federal agency roles and assigned tasks regarding Federal assistance to State and local governments in their radiological emergency planning and preparedness activities. As a part of these regulations (44 CFR 351.10), the FRPCC was established to assist FEMA in providing policy direction for the program of Federal assistance to State and local governments in their radiological emergency planning and preparedness activities. As a result of this new regulation, the Federal Interagency Task Force on Emergency Instrumentation for Nuclear Incidents at Fixed Facilities was renamed the FRPCC Subcommittee on Offsite Emergency Instrumentation for Nuclear Incidents, hereafter referred to in this document as the Subcommittee.

Emergency response to a nuclear reactor accident is expected to be coordinated between the licensee, State and/or local organizations, and Federal agencies. The primary role of State and local governments is to mitigate the risks to the health and safety of their constituent populations through the implementation of protective actions in their jurisdictions. In order to implement these actions, the State and/or local governments will require radiological information based on emergency radiation measurements for verification of protective actions already implemented, and initiation, control, and cessation of additional protective actions. This radiological information can initially be derived from projections based on onsite measurements and from offsite measurements made by the facility, but later primarily by measurements made by State and/or local organizations, and/or by Federal agencies. While initial actions will be based on information from the facility, later offsite measurements will play a necessary role in determining if further actions are needed to protect the public.

Nuclear facility licensees are required to monitor the plant environs for radioactivity that may be released from normal operation and from accidents (10 CFR 50 - Appendix A).[7] They are also required to develop an emergency plan that includes monitoring the facility itself and the onsite and offsite environs for prompt detection and continued assessment of an accident (10 CFR 50 - Appendix E).[8] The radiological information from the onsite emergency radiation measurement systems will be of prime importance for the implementation of immediate protective actions by the State and/or local governments in accordance with their formalized emergency response plans.[9] The State and/or local governments also need an emergency radiation measurement system for offsite emergency monitoring to supplement the radiological information derived from the facility's measurement systems in order to implement necessary protective actions and subsequent recovery efforts. The offsite emergency response capability requires thorough coordination of all aspects of the response plan with the nuclear facility management to assure close cooperation and a rapid and positive response in the event of a nuclear accident.

In an effort to consolidate the Federal response to a wide range of potential radiological emergencies, FEMA has coordinated the Federal interagency development of a Federal

Radiological Emergency Response Plan (FRERP).[10] Included in the scope of FRERP are all types of civil radiological emergencies that might require a significant Federal response in support of State and local governments. Under FRERP, if a serious radiological accident were to occur, the Department of Energy's (DOE's) Radiological Assistance Program (RAP) and the Federal Radiological Monitoring Assessment Plan (FRMAP) can provide comprehensive emergency radiological monitoring capabilities for supplementing the State's and/or local organization's emergency radiation measurement systems (see Appendix A). However, these Federal capabilities may not be available at the scene for 12 to 18 hours after receiving a request for assistance. Consequently, the most acute need by State and/or local organizations for their own offsite emergency radiation measurement systems will be during the first 18 hours or so after the start of the accident.

The most workable design for the offsite emergency radiation measurement system involves a compromise between the ability to describe the time history of the extent and magnitude of contamination from the radioactive release, and the information that is necessary to implement timely protective actions that achieve the greatest health benefit. For example, the number and locations of measurements, the times at which they must be made, the types of measurements, accuracy, bias, and other system characteristics represents a balancing between the desire to describe the radiation accident and the fact that protective actions, if they are to be effective, must be complete within specific time constraints. The recommendations of this report present guidance on use of offsite emergency radiation measurement systems to provide data as a technical basis for the verification of protective actions implemented during and following an airborne release. These recommendations are consistent with the planning basis for the development of State and local government radiological emergency response plans in support of light water nuclear power plants, planning basis document NUREG-0396, EPA 520/1-78-016.[11]

1.1 Scope of This Report

The measurement systems that are recommended in this report are state-of-the-art instrumentation and techniques for monitoring exposures from radioactive releases from light water nuclear power reactors. Comments from other government agency reviews of this report have been taken into consideration in developing this guidance. The basis for omission from the report of other systems and techniques that would be of equal quality for this type monitoring is that the FRPCC Subcommittee was constrained by the need to keep the report content within reasonable bounds in order to promote workable guidance.

The FRPCC Subcommittee Phase 2 and Phase 3 guidance address the offsite Emergency Radiation Measurement Systems needed to implement protective actions for the milk and the water and non-dairy food exposure pathways, respectively. A future Phase 4 document will address guidance on recovery and reentry.

Two offsite emergency radiation detection and measurement systems are defined for use in collecting data to be used in determining protective actions against direct exposure to the plume or airborne release from a nuclear accident. One system is to provide offsite measurement to confirm and supplement the data provided by the facility in its notification of a nuclear incident to the State and/or local EOC. This system is the Plume Exposure Rate Verification System, which is discussed in Section 4. The information provided to the EOC by the facility's nuclear incident notification process is described in Section 3. The second system is for measuring the accrued exposure from the plume to emergency workers. This Emergency Worker Exposure Monitoring System is discussed in Section 5.

These offsite emergency radiation measurement systems operated by State and/or local organizations together with the emergency plans of the nuclear facility and Federal agencies are designed for implementing offsite protective actions for accidents requiring such action, as conceived in the guidance provided by NUREG-0396.[12] It is believed that these radiation measurement systems and emergency plans will also be adequate for those less severe incidents that may require offsite protective actions as well as design basis accidents.

1.2 Conceptual Guidance

Protective actions, as used in this document, are those actions taken to avoid or reduce the projected dose from a nuclear accident when the benefits derived from such actions are sufficient to offset any undesirable features, e.g., risk of traveling in adverse weather, unreasonable cost or hardship on participants, of the protective actions. A Protection Action Guide (PAG) is the projected dose, from exposure to airborne radioactive materials, to individuals in the population which warrants taking protective action. Projected dose is defined as that dose that would be received by the population if no protective action were taken.

For PAGs, the projected dose does not include dose that may have been received prior to the time of estimating the projected dose.[13] A PAG does not imply an acceptable dose. (See Section 4.0 for a discussion of PAGs).

Protective Action Guides and guidance on the implementation of protective actions are being developed cooperatively by various Federal agencies[14] for use by State planners to develop State radiological emergency preparedness plans. The PAGs are projected whole body or thyroid dose limit ranges which require protective actions. Since the PAGs are related only to whole body or thyroid doses, skin dose limitation will not be addressed in this document.

The FRPCC efforts in their development of radiological emergency preparedness guidance have been directed first towards light water nuclear power reactor accidents. If additional guidance on other types of radiological emergencies becomes necessary, it will become the subject of a separate guidance document.

The guidance reports on offsite emergency radiation measurement systems to be written by the FRPCC Subcommittee will usually follow the issuance of guidance on the implementation of protective actions. However, the recommendations of the original FEMA REP-2 report on Phase 1 of the Airborne Release were developed concurrently with the Federal interagency effort on development of PAGs and guidance on the implementation of protective actions.[15]

Insofar as possible, the FRPCC Subcommittee strives to define measurement systems that use instrumentation readily available to the States and/or local organizations at little cost, and which are useful in other normal and emergency radiation measurements. In this respect, it is important that each State or local organization review the adequacy and availability of its equipment for emergency monitoring. This is not intended to imply that more expensive and/or sophisticated equipment can not be used, if available.

Conceivably, the aggregation of the available instrument resources recommended for individual emergency radiation measurement systems may not be the most cost-effective mix of instrument resources for the emergency radiation measurement systems as a whole, i.e., the total system.

The generic instruments and equipment requirements and other resources recommended by the Subcommittee for use in offsite emergency radiation measurement systems are as follows:

1. Plume Exposure Pathway.

    - Direct exposure measurements - calibrated low-range (0-50 mR/h) and high-range (0-100 R/h) survey instruments. GM or sealed ion chamber type instruments with moveable beta shields on the low-range instruments to provide open and closed window measurement capabilities.
    - Radioiodine measurements - calibrated air pumps with appropriate particulate filters, cartridge type adsorber filters (such as silver zeolite) for selective collection of radioiodine in the presence of noble gases. A thin window (1.5-2.0 mg/cm^2) pancake type GM detector or a 1" x 1" or 2" x 2" NaI(Tl) detector with either a single channel or dual channel analyzer may be used to measure the radioiodine activity on the adsorber cartridge.
    - Personal dosimetry - calibrated direct reading dosimeters and permanent record dosimeters (see emergency worker exposure instrumentation).
    - Dose projection capability - a hand-held calculator is adequate for making thyroid dose rate projections in the field based on the field measurement data. However, a more sophisticated computer program may be desirable at the Emergency Operations Center (EOC). This program should have the capability of making dose projections based on release measurements obtained from the plant operators as well as the capability of accepting field measurement data as input for fine tuning the dose projections.
    - Communications – direct and, ideally, continuous communications ability is necessary between the field monitoring teams and the EOC or Forward Command Post. This is best accomplished by means of radio with backup systems, such as additional radios or public telephones, available in the event of equipment failure.

2. Ingestion Pathway (see References 11 and 12).
3. Other Resources.

    - Utility - the utility offsite field monitoring teams will be able to mobilize and respond to a potential offsite release of radioactivity more quickly than the State or local field monitoring teams. The offsite measurements made by the utility field monitoring teams should be used for early delineation of the plume boundaries and verification of initial dose projections. The combined measurement data from the utility and State or local monitoring teams will provide a better overall characterization of the plume. The utility may also be a resource for additional monitoring team personnel and monitoring instruments or equipment.
    - Federal Agencies - several Federal agencies have the capability of providing personnel and equipment resources for additional field monitoring and sample collection teams and radiological laboratory facilities (both mobile and fixed facilities). In addition, the Department of Energy (DOE) has the Aerial Measuring System program which should be used following releases of radioiodine or particulate radioactivity to determine the areal extent of ground surface radiological contamination caused by the deposition of radioactivity from the plume. During the course of an airborne release of radioactivity,

dose projections, and predictions of ingestion pathway concentrations from DOE's Atmospheric Release Advisory Capability, an atmospheric modeling system based at Lawrence Livermore National Laboratory, may be available to State and local authorities.

2 BASIC CONSIDERATIONS AND ASSUMPTIONS FOR GUIDANCE ON OFFSITE EMERGENCY INSTRUMENTATION

The technical basis for the FRPCC Subcommittee guidance on Offsite Emergency Instrumentation, in this document and subsequent documents in this series,[16] relies on concepts developed by the FRPCC Subcommittee, background documents from the Environmental Protection Agency (EPA) Manual of Protective Action Guides and Protective Actions for Nuclear Incidents[17] and information in other reports.[18] The need for guidance on emergency instrumentation is to provide added assurance that the health and safety of the population surrounding the site is protected and that their radiation dose is minimized in the unlikely event of an accidental release of airborne radioactivity as described in NUREG-0396.[19] The approach taken in developing the guidance was to examine systematically the process; 1) for performing radiation measurements, 2) for converting the measurement into useful radiological information, and 3) for using this information to determine effective protective actions.

2.1 Protective Action Decision Making

The emergency decision maker will require many kinds of information, including radiological information derived from onsite and offsite radiation measurements. The initial precautionary protective action recommendations, e.g., do nothing, shelter, evacuate, etc., should be based on plant status parameters provided by the utility. These onsite plant parameters will normally be available to the decision maker before an assessment can be made of the measurements from an offsite radioactive release. The offsite radiation measurement data should be used to verify that the protective actions taken, based on the onsite plant parameter data, were extensive enough to adequately protect the public.

For protective actions to be most effective, the selection from available alternatives must be made at the most opportune time. This act of making a decision can be expedited if the decision maker is provided with criteria for determining that a decision should be made, i.e., the PAGs.[20] Other criteria for choosing among the available protective action alternatives must be determined by the planner because these criteria are usually site dependent. The decision making process can be further expedited if the information received by the decision maker is directly comparable to the criteria.

The primary value of radiation measurements is to provide information for use by the decision maker for verifying if the protective action taken, based on projected radiation levels, was correct or if protective action recommendations are necessary for additional areas. For example, local meteorological or topographical conditions may cause the offsite radioactive plume to behave different from the projections based on the onsite plant data, e.g., localized areas of higher radiation levels or actual plume boundaries which differ from those projected by the calculational models. The amount of data provided must be adequate to make the most effective decision. Only necessary data need be taken and evaluated, because consideration of extraneous data will contribute to delay of the decision making and will waste resources that may be scarce during an emergency.

The systematic acquisition of data from offsite field measurements and conversion to information for use in the decision making process is diagramed in Figure 1. Also the application of this approach in deciding whether to shelter or evacuate a population to prevent an inhalation exposure to radioiodine is presented in Figure 1. (The same principle can be applied to the use of field measurements for verification of whole body exposure.) The use of field monitoring data to revise protective action decision making could follow this scenario. Assume that prior to the airborne release of radioactivity from a serious nuclear power plant accident, protective actions are being taken to evacuate the population in all directions within two miles of the plant site and five miles down wind from the site in a sector covering approximately 68 degrees. A population center located approximately 10 miles from the plant site is not included in these protective actions. When the actual release occurs, field measurements near the site boundary indicate that the projected whole body dose and path of the plume are in error due to a release that is much larger than anticipated and defects in the meteorological models used in the projection. Based on these data, the revised whole body dose at the population center is estimated to exceed 1.0 rem. Revised protective actions to evacuate or shelter persons within this population center can be made; depending on the time available and needed to carry out the action as well as other considerations (e.g., estimated duration of the release, weather conditions, meteorological forecasts). Although it is not illustrated in Figure 1, this approach can also be used to determine the time within which the measurements must be made in order to verify that the protective actions will be effective. This is accomplished by comparing the time required to make the field measurements, processing the data, interpreting the information, and communicating the decisions with the time available prior to implementing the protective action.

The EOC is considered a focal point for gathering information, making decisions, and communicating with the facility and organizations (e.g. local, state or Federal) involved in a nuclear accident. The first off-site organizations to be involved are local, followed by State, Federal and other organizations. The first protective action decisions should be based on a projected dose pattern provided by the nuclear facility.

An outline of an effective data-to-information conversion system (modified to meet local constraints) can be developed by the planner from the guidance provided in this report for each class of PAGs. The offsite emergency field measurement requirements for a specific emergency plan can also be identified. These specific measurement requirements and instrumentation needs must, of course, be responsive to the local planning situation including the hypothesized type and size of the radionuclide release for the Emergency Planning Zones (EPZ)[21] under consideration.

Please see attached Image – Figure 1.

Figure 1. Illustration of the Systematic Conversion of Radiological Measurements to Information of the Decision Making Process for Protective Action Planning

2.2 Release Composition

Two important factors affecting the composition of the release from a reactor accident are the volatility of the fission products concerned and the status of the reactor with respect to its operating history and time since shutdown. Reactor operation produces large quantities of radionuclides within the fuel. The amount of each radionuclide accumulated in the reactor is dependent on several reactor operating parameters including the type of reactor, type of fuel, operating history of the reactor, power level of the reactor, length of time at that level, and the length of time between reactor shutdown and the release.

The most important radionuclides available for accidental release from a reactor in terms of potential health effects will probably be the radio-iodines[22] , of which I-131 is the critical component. However, the health effects of releasing other fission-product radionuclides cannot be ignored. Important among these are the isotopes of tellurium, strontium, cesium, cerium, ruthenium, and the noble gases, krypton and xenon.

In spite of the fairly definitive information available regarding the inventories of radioactive material in reactor cores for different types of reactors with different operating histories, there are many important factors which influence the quantities and relative amounts of those materials which may contaminate the environs during an accident. Included are preferential releases of the more volatile components, such as noble gases and radioiodine. Radioactivity plate out from a release, and the effectiveness of engineered safeguards such as filtering systems and building containment are important in retarding releases. It should also be clearly recognized that releases calculated for accidents are only estimates. At best, they provide an order of magnitude indication of the extent of the emergency environmental monitoring which might be required at the time of an accident. Guidance on the anticipated radionuclides which may be accidentally released to the atmosphere is given in NUREG-0396 pp 22-23.[23]

2.3 Dispersal of Radioactivity to the Environs

In the case of a serious reactor accident, the most likely route of dispersing radionuclides to the offsite environs is through release to the atmosphere. Less likely modes of dispersal are release of radionuclides into surface waters, or by leaching into underground water supplies. The emergency environmental radiation monitoring program must be sufficiently comprehensive to assess the significance of all the important contaminants that may be released to the environs. However, a useful simplification in planning emergency environmental monitoring is to consider radio-iodines as the most critical radioactive material to be immediately measured in the field. The field measurements must include collection of samples for later examination at a laboratory.

Comprehensive planning is required for emergency environmental radiation monitoring following a nuclear accident because the combination of a large fission product inventory in the reactor and the possibility of atmospheric dispersal could result in widespread contamination of the environs. In general, emergency environmental radiation monitoring plans that are based on atmospheric dispersal of radioiodine as the principal radionuclides of concern, should also provide adequate preparedness to measure other radionuclides dispersed by the atmosphere or other routes. Emergency monitoring plans for a specific site must include emergency instrumentation appropriate for measuring the radionuclides that may be released.

Radioactive materials released to the atmosphere from a nuclear accident in the form of gases or aerosols are mostly dispersed by turbulent diffusion in the air. The released material, in the form of a radioactive cloud, will move downwind under the existing meteorological conditions. Material initially in the form of aerosols may be deposited from the cloud on the ground or may be carried down by rain or snow. It is feasible, by the application of theories concerning turbulent diffusion and on the basis of a number of plausible assumptions, to estimate the radioactivity concentration pattern and exposure rate pattern resulting from the passing cloud. The projected dose can be calculated from the time integral, the concentration of airborne radioactive material, and appropriate dose conversion factors. It is also feasible to calculate the estimated concentrations of deposited radioactive material by applying estimated deposition velocities to the airborne concentration and the time interval for exposure to the plume. Predictions of exposure rate patterns are essential for making initial protective action decisions. Also, these predictions are needed in the planning and implementation of the offsite emergency radiation surveys to confirm the presence or passage of the radioactive plume.

2.4 Radiation Exposure

A variety of exposure modes to persons are associated with a release of radioactive gases or aerosols to the atmosphere. They include:

a. Whole body exposure to external radiation from:
    i. the radioactive cloud,
    ii. radioactive materials deposited on the ground or other surfaces, and
    iii. radioactive materials deposited on the skin or clothes.
b. Internal exposure to radiation following the inhalation of airborne radioactive material or resuspended deposited material; and
c. Internal exposure to radiation following ingestion of contaminated food or water.

Some types of exposure may begin very soon after the release; for example, exposure to external radiation from the cloud or inhalation of airborne material. Other types of exposure may begin at a later stage and could persist over a long period of time; for example, the ingestion of deposited radioactive material in its progression through food-chain pathways.

Since radioactive materials may be rapidly dispersed over substantial distances following a release to the atmosphere, emergency monitoring over a large area may be required to determine the concentrations of airborne and deposited material. It should be recognized, however, that some human exposure to the radioactive cloud cannot be avoided if the decision to implement protective action is based only on measurements at the exposure site, because exposure will occur during the period of measurements, analyses, and protective action implementation. Furthermore, continued environmental measurements will be required over an extended period of time after the release has ended to follow the movement of contaminants through food-chain pathways.

The objectives of any emergency monitoring program are to supply the information needed: 1) to confirm or modify protective actions taken to limit radiation exposure to members of the public, 2) to indicate need for further actions, and 3) to determine when actions should be terminated. Moreover, at the planning stage, the consequences of the types of accidental releases to the environs as described in NUREG-0396[24] must be assessed in order to determine the extent of the emergency monitoring required. The information from emergency monitoring must be used in conjunction with the PAGs, to establish a basis upon which to take protective actions. Appropriate PAGs are discussed in the EPA Manual (EPA-520/1-75-001).[25]

2.5 Emergency Measurement Systems

The FRPCC Subcommittee has concluded that the following offsite emergency measurement systems are required for determining whether the airborne radioactivity levels will exceed the PAGs (see also Section 3):

a. A Plume Exposure Rate Verification System to verify estimated radiation exposure rate patterns and to provide supplemental information to support decisions to take protective actions within or beyond the EPZ for the Plume Exposure Pathway.[26]

b. An Emergency Worker Exposure Monitoring System as a basis for decisions to curtail activities of emergency workers (Emergency Worker PAGs).[27]

c. An Ingestion Pathway Monitoring System to provide data for decisions to allow or disallow the use of foodstuffs grown within the EPZ for the Ingestion Pathway.[28]

d. A Recovery and Reentry Monitoring System to provide data for decisions to permit individuals to return to evacuated areas or to restore contaminated areas to pre-emergency status. This latter system is not truly an emergency system, but is required to determine the end of the emergency in a timely fashion.

These emergency systems, their purpose, and when measurements should be made in terms of the time progression of the incident, are illustrated in Figure 2. Each system is independent of the others in the sense that each system acquires a specific set of measured data that provides specific information which is required at a specific time. On the other hand, these systems are interdependent in the sense that: (1) the data acquired by one system may supplement the data acquired by another system, (2) the information derived by one system may be useful for implementing another system, and (3) most of the resources (instrumentation and manpower) may be interchangeable among the systems.

See attached Imagine – Figure 2

Figure 2. Summary of Measurements and Information for Each Offsite Radiation Measurement System versus Time Period (or Phase) of a Nuclear Incident

The first protective action expected to require implementation is avoidance of exposure to total radioactivity in the plume and to inhalation of the radioiodines in the plume. This protective action, if required, must be implemented without delay in nearby downwind areas. This initial decision should be based on projected dose patterns made by the facility. However, the accuracy of projected dose patterns will decrease with distance from the facility and with time after the start of the release. This is because the amount of information known about the prevailing meteorological conditions probably will be limited and the micrometeorology affecting plume size, direction and concentration is extremely complicated. Subsequent decisions to implement protective actions against external radiation exposure or inhalation of radioiodines at distances of more than several miles from the facility are expected to be based on rather inaccurate projected dose patterns. Consequently, exposure rate measurements at selected times and locations to correct and update projected exposure rate patterns and the derived dose patterns are needed to improve their accuracy.

The primary function of the Plume Exposure Rate Verification System is to provide a flexible means to correct, verify and extend these projected dose patterns. As indicated in Figure 2, data from this system will be required from the start of the accident until the airborne release has dissipated. In addition, some of the supplementary measurements required, such as measurements of the radioiodine concentration in air, gross measurements of airborne particulates, and gamma radiation exposure rate measurements at the edge of the plume and at the plume centerline (discussed in Section 4), can be used as preliminary data for the initiation of Ingestion Pathway and Recovery Reentry Monitoring Systems and for planning emergency missions.

The accrued external gamma dose for emergency workers from exposure to the plume, or to deposited material, must be monitored throughout the accident as indicated in Figure 2 and discussed in Section 5. Also, the accrued thyroid dose must be estimated for emergency workers exposed to the airborne release. In addition, the gamma exposure rate and the radioiodine and radioactive particulate concentrations in air should be measured at emergency workers', e.g., traffic controllers, field monitors, etc., assigned locations within in the airborne release pattern to determine the exposure time available to emergency workers to carry out their tasks.

In the event of a long-term release, some measurements in the ingestion pathways may be needed before the airborne release has dissipated. However, most of the effort needed for Ingestion Pathway and Recovery Reentry Monitoring will occur after the end of the release as indicated in Figure 2. Consequently, the resources needed for plume exposure rate measurements can be transferred to these measurement systems. For example, the manpower could be used to acquire samples, and some of the instrumentation may be useful for gross gamma or beta radiation screening of samples.

3 NUCLEAR INCIDENT NOTIFICATION AND DOSE PROJECTION

The nuclear facility's emergency plan must provide for notification to the appropriate State or local agency as soon as possible[29] that an abnormal release with offsite consequences, e.g., a Site Area Emergency or a General Emergency Class of accident[30] may occur, or has occurred. Prompt initiation of the State radiological emergency preparedness plan is necessary to implement any required protective actions. Therefore, full advantage must be taken of available warning time before the potential offsite release to implement the preliminary stages of the emergency response plan. Accordingly, the FRPCC Subcommittee recommends that the NUREG-0654[31] guidance on prompt alerting and notification be followed in the State and the utility emergency response plans, and that a required sequence of emergency action classification levels are issued by the nuclear facility. The first emergency action level will be in advance of a probable offsite release so that protective actions can be anticipated and preliminary response coordinated. This information should be forwarded to the designated offsite officials, e.g., to the EOC in accordance with preplanned response procedures which provide for expeditious notification.

3.1 Onsite Nuclear Incident Detection and Notification System

Although this report addresses offsite emergency instrumentation, the FRPCC Subcommittee feels that data required for alerting, warning, and notification of plant conditions and of a potential offsite release and for initial dose projections are best acquired by the nuclear facility through use of radiation detection and measurement systems operated onsite by the facility.

Nuclear Regulatory Commission (NRC) regulations establish minimum requirements for the principal design criteria for water cooled nuclear power plants in 10 CFR Part 50, Appendix A.[32] Criterion 13 of Appendix A requires instrumentation to monitor variables and systems for accident conditions (and for normal operation) including those variables and systems that can affect the integrity of the core, reactor coolant pressure boundary, and the containment. By observing instrumentation readouts, the operator can monitor the integrity of systems designed to contain radioactivity and the operation of systems, such as the emergency core cooling system, designed to mitigate the consequences of accidents. Should the plant process instrumentation indicate that a significant accident, such as a break in the reactor coolant boundary, has occurred, it would require the proper emergency classification be declared and transmitted promptly by the site operations staff to the designated EOC director or other appropriate offsite authorities.

Criterion 64, Appendix A of 10 CFR Part 50[33] requires means, and USNRC Regulatory Guide 1.97[34] provides guidance for meeting this requirement, for monitoring any radioactivity released to the reactor containment atmosphere, the spaces containing components for recirculation of cooling water for the core, the effluent discharge paths and the plant environs during normal operating and accident situations. By appropriate calibration, location, range and shielding of such instrumentation, the operator can deduce the effectiveness of core cooling and determine whether any radioactivity within the containment building is due to: 1) the release of primary coolant water into containment, 2) the release of activity in fuel-cladding gaps through cladding perforations, or 3) some further core degradation. NUREG-0654 describes the content requirements of emergency plans to be acceptable to FEMA and the NRC.[35] Should initial efforts to control an accident be unsuccessful, or subsequent failures of emergency reactor systems make a release of radioactivity probable, a higher level of emergency classification notification, that of site area or general emergency, will be issued to the EOC director. Such a warning will include a forecast of the likely direction and rate of travel of any release based on onsite meteorological instrumentation and other local meteorological information as well as a protective action recommendation. Should it subsequently occur that in spite of efforts to control the emergency, significant quantities of radioactivity are released to the environs, this information as well as a projection of offsite doses must immediately be given to the EOC director.

3.2 Offsite Fixed Detection System

The FRPCC Subcommittee did consider the use of a ring of offsite gamma-sensitive detectors. Such a system cannot guarantee an early warning of a release, as recommended above, and it would be expensive to install and operate as discussed in NUREG/CR-2644.[36] Since this type of monitoring system cannot guarantee the detection of all offsite releases, the use of fixed offsite monitors for emergency response purposes for initial detection of an airborne release is not recommended. Because measurement of the release can be achieved more rapidly and more accurately by facility sampling, the FRPCC Subcommittee advises that appropriate arrangements be made with the nuclear facility to provide advanced warnings of anticipated releases and dose projections.

3.3 Projected Dose Patterns

The facility operator is required to furnish the downwind projected dose estimates to the EOC[37] under accident conditions. These dose estimates will be upgraded promptly whenever changes in the source term or local meteorology occur. In addition, to be consistent with the elements listed in NUREG-0654, the data input used to make the dose estimates should be made available to the EOC on request. Dose Projections could be made using one or more of the methods described in Appendix B.

4 PLUME: EXPOSURE RATE VERIFICATION SYSTEM

Upon receipt by the EOC of a nuclear incident release notification, implementation of the initial protective actions in the EPZ[38] will begin. The proper offsite authorities and the licensee will receive or make initial projected dose patterns based on facility information for the purpose of determining protective actions to minimize population exposure from the airborne release. Two potential systems are described in Appendix B for calculating projected dose patterns. One system is an onsite dose projection system operated by the facility. The other is an offsite dose projection system which would be operated by the State or local EOC to supplement the onsite system. By use of the offsite dose projection system and with timely meteorological data, projected dose patterns are made and used, if necessary, as a basis for making protective action decisions in the absence of adequate onsite data (Appendix B, Section 3). It should be noted that differences, e.g., 10 times, are to be expected between the projected exposure rates and the actual field radiation measurements at any given offsite location.

The EPA's PAGs[39] for projected exposure of the general public by the airborne plume containing radioactive noble gases and radioactive iodines are shown in Table 1. The PAGs are expressed as projected dose ranges. Where the projected dose exceeds the lover end of the PAG range, responsible officials should consider initiating protective actions particularly for the more sensitive populations. Where the dose projected is at or exceeds the upper end of the range, responsible officials should take protective actions to protect the general public unless the protective actions would have greater risk than the projected dose.

Table 1. Protective Action Guides for Projected Exposure of the General Public by a Radioactive Airborne Plume[a]

Protective Action	Whole Body Exposure	Thyroid Exposure
Shelter or Evacuaation	1-5 rem	5 - 25 rem

a Reference 1 (pages 2.3 and 2.5)

At projected doses below the lower end of the range, responsible officials may suggest voluntary action available to the general public at risk. This should be done with the philosophy that populations doses be kept as low as possible as long as the effects of the protective actions are not more hazardous than the projected dose.

According to the EPA, when ranges are shown, the lowest PAG value should be used if there are no major constraints on providing protection, such as sheltering, at that level. Local constraints may make lower values impractical to use, but in cases where the projected dose exceeds the higher value, there is clearly a need for protective actions, e.g., either shelter or evacuation or a combination of both. Emergency planners for State and local governments need to establish criteria for protective actions to be taken based upon the projected exposure ranges given in Table 1. Although PAGs for organs other than the thyroid have not yet been established, the EPA has advised the Subcommittee that interim guidance for PAGs on inhalation exposure to other organs should be in the range of 1 to 5 rem.[40] Therefore, a Plume Exposure Rate Verification System is needed to provide measured data that can be used to correct, update, or verify calculated projected dose patterns as shown in Figure 2.

The following point is emphasized; the projected dose, (i.e., dose delivered over a future time period), at a specific point is a function of the time integral of the projected exposure rate at that point. Consequently, the two resources (described in Appendix B) for calculating projected dose patterns from onsite data are based on integrating over time the projected gamma exposure rate patterns that are calculated from measurements (or estimates) of the source term release and the prevailing meteorological parameters. A method to verify these calculations is to measure the gamma exposure rate pattern at a specific time and to compare the results to the projected pattern for that time. It should be noted that a single measurement from the Plume Exposure Rate Verification System represents only one point in time. Therefore, it is necessary to have several measurement points and a traverse of the plume to provide delineation of the actual plume position. After establishing the plume location, an air sample must be collected at or near the plume centerline in order to provide air concentration measurements which can be directly compared with the projected centerline concentration, and hence exposure rate. Centerline measurements are also necessary in order to project exposure rates at other downwind distances.

One of the main purposes of the offsite Plume Exposure Rate Verification System is to verify the projected exposure rate pattern from the onsite system that was made at an earlier time (t_0) for the specific time (t_1) and correct the projection, as necessary. In addition, it can be used together with other data to estimate the projected exposure rate pattern for a future time (t_2) in the event onsite data or projections cannot be obtained (i.e., loss of communications or effluent monitors). The manually operated offsite dose projection system (described in Appendix B) is a second use of the data from the Plume Exposure Rate Verification System.

The complete delineation of the extent and magnitude of an airborne release is difficult under stable weather conditions and next to impossible under unstable conditions. The difficulties in plume monitoring are a result of variability of the source, the continuous vertical and horizontal movement of the plume, changes in meteorological conditions (temperature gradient, wind speed and direction), effects of local topography and problems of access and logistics. Fortunately, most of these factors which make it difficult to locate and monitor the plume result in a greater dispersion of the plume and hence lower concentrations and projected doses. Thus, the situation of most concern is that of stable conditions which will result in a more defined plume that should be easier to locate, delineate and determine the maximum concentrations. In this instance, action may be required only in certain sectors of the EPZ. This is not to imply, however, that all conditions which result in projected doses that are significant off site will have a well-defined plume moving in the downwind direction. Factors such as wind shears and local topography may result in plumes moving in two directions, pockets of high concentration or other adverse effects. The Subcommittee concludes that the well-defined plumes under stable conditions will represent the greatest hazard at the farthest distance from the site. Additionally, under extremely stable conditions, elevated and continuous releases will have such little dispersion that ground level measurements may not be in the plume even at distances of a mile or more from the point of release.

Offsite monitoring should be capable of making measurements under these conditions. If necessary, aerial gamma radiation surveys made by the DOE Aerial Measurements System (Appendix A) or by the local Civil Air Patrol may be used to locate the position and determine the relative strength of the elevated airborne plume. It is necessary to have this information about an elevated airborne plume in order to determine if modifications are required for protective action decisions made for areas within, or in some unlikely instances, beyond the EPZ[41] for the plume exposure pathway. Information on the presence or absence of large airborne concentrations at locations distant from the site under variable wind conditions can also be important in determining protective actions.

4.1 Methods of Verifying Exposure Rate Patterns

Four methods for making measurements to verify the patterns of the estimated exposure rates from an airborne release have been identified as follows:

1. Measure at a large number of points in a pre-planned grid pattern that is centered over the downwind line relative to the facility.
2. Measure radiation levels across the plume at two or more distances downwind of the facility and measure the maximum levels at the plume centerline.
3. Measurement of air samples collected from within the plume at or near the plume centerline.
4. Measure at a few points close to the facility to determine the centerline exposure rate and extrapolate downwind by an R-1 approximation, where R is the downwind distance from the facility. This approximation assumes that the plume centerline exposure rate is inversely proportional to the downwind distance from the release point. This approximation should prevail whenever dose measurements are made outside 1700 meters from a reactor for Pasquill Condition C and shorter distances for Conditions A and B. For Pasquill Condition D, good R-1 estimates could be obtained at about 5000 meters. For a discussion of the technique, see page 5.10 of Reference 1.

The above verification techniques are addressed to one set of measurements. For a release of long duration, projected patterns may require reverification particularly whenever meteorological conditions, release rates or release composition change significantly.

4.2 Measurement Options

The dose contributors in an atmospheric release are expected to be the iodines and other volatiles, noble gases, and fission product particulates. If the release composition is that postulated in the EPA manual,[42] then the dose to the thyroid from inhalation of radioiodines is expected to be the major dose contributor, and this dose is approximately 400 times the whole body external gamma dose from the plume.

Consequently, the projected thyroid dose pattern from inhalation of radioiodines could be conservatively estimated by determining the whole body external gamma dose pattern (from gamma exposure rate measurements and estimated duration of exposure) and multiplying the values by a factor of 400. However, if in the likely event that the release composition is not as postulated by the EPA manual, then this method could lead to significant errors which could result in the unnecessary initiation of protective actions at long distances from the facility.

A single ground level gamma exposure rate measurement does not distinguish between the exposure rate contributions from radionuclides deposited on the ground, from radionuclides in the overhead gaseous plume, or from radionuclides in a ground level gaseous cloud (one in which a person is immersed). Consequently, a ground level measurement may be due to any one or any combination of the above contributions.

If only gamma exposure rates are measured, and a multiplication factor of 400 is used, a large error in projected thyroid dose may occur. Therefore, it is recommended that the radioiodine and particulate airborne concentrations be measured at a representative number of locations. Measurement of particulate radioactivity is of lesser importance than radioiodine with respect to dose impact when compared to whole body or thyroid dose during the release. However, the sample may be of value for making decisions concerning ingestion pathways or deposited materials problems.

4.3 Radionuclides Other than Radioiodine that Require Monitoring

Accident sequences from an extensive report, "The Reactor Safety Study" (RSS),[43] were evaluated and other existing literature was reviewed to determine radionuclides that could contribute dose from the airborne plume. The example accident sequences from pressurized and boiling water reactors that are used in this section are presented in Table 2. Tables 3 and 4 present the ratio of potential inhalation dose to PAGs, e.g. a 1 rem dose for whole body or organs other than thyroid and a 5 rem dose for thyroid, for radionuclides that are associated with these accident sequences. The importance of, and monitoring of, these radionuclides are discussed in the following paragraphs of this section.

It is not within the scope of this report to discuss the probabilities of potential accidents in nuclear facilities. Although some aspects of the RSS have been questioned and further work is in progress to resolve the questions, the RSS does provide a range of potential radionuclide source terms. The amount and types of nuclides released will depend on the specific accident sequence. The RSS divided the radionuclides present in a reactor core into several categories based on their post accident behavior. In all accident sequences, a higher fraction of the core inventory of noble gases will be released than any other group of nuclides.

Table 2. Description of Two Examples of Reactor Accident Sequences

See attached image – Table 2

Table 3. Ratio of Inhalation Dose to PAG for A PWR Accident Scenario Dose to Teenager via Inhalation

See attached image – Table 3

See attached image – Table 3

Table 4. Ratio of Inhalation Dose to PAG for A BWR Accident Scenario Dose to Teenager via Inhalation

See attached image – Table 4

In all but the least serious accident release categories, the radioiodines are predicted to be released in the next highest fraction of the core inventory.

This section discusses the dose effects and monitoring of particulate radionuclides, all nuclides except the noble gases and an unknown fraction of iodines. Ongoing source term studies indicate that the postulated radioiodine source term for most accidents may be a factor of ten lower than the RSS source terms. However, with respect to potential dose, radioiodine is still the dominant radionuclide. A comparison of radioiodine, noble gas, and particulate radionuclide hazards are presented in Section 4.3.1.

To demonstrate the differences in potential dose resulting from exposure to gaseous and particulate radionuclides, two accident sequences are presented. These accident sequences are examples of less severe but more probable release categories in the RSS. The same emergency planning is required for all accidents. However, in the more severe accidents, larger radionuclide concentrations will be present at greater distances from the reactor site. The example accidents presented here are intended to illustrate situations requiring monitoring and are not intended as specific accidents on which to base emergency plans.

The accident scenarios in the RSS are put in sets called release categories based on the size of radioactive release. Each release category is numbered, with group 1 having the greatest release fraction and group 9 the least. The first example accident shown in Table 2 is designated PWR-7 AHG-epsilon by the RSS (See Appendix C). The PWR-7 signifies the release category for a pressurized water reactor while AHG-epsilon denotes a specific accident sequence. AHG-epsilon is a large loss of coolant accident (LOCA) with failure of the emergency core cooling system (ECCS) in the recirculation mode and failure of the containment heat removal system. Containment integrity is lost when the core melts through the containment base mat. The second accident, the BWR-5 A accident, is for a boiling water reactor in which the reactor coolant boundary is ruptured but all engineered safety features operate as designed.

Based on the evaluation of these two RSS accident scenarios, the nuclides of concern other than the radioiodines (which contribute significantly to dose) are Te, Cs, Sr, Ru, and Ce. The Cs and Sr isotopes will generally give the highest dose. However in some accident time segments due to differing core inventory release rates for different element groupings, the Ru-106 nearly equals the Sr-89/90 dose and must also be included (See Appendix C).

NUREG-0396[44] also considered a broad range of accident scenarios to determine radionuclides that could contribute to dose from the airborne plume. In addition to the range of RSS accident scenarios (Class 9)[45], the document also considered environmental reports, i.e., best estimate Class 1 through Class 8 accidents and Design Basis Loss of Coolant Accidents (DBA/LOCA). NUREG 0396 concluded that "environmental report discussions (Class 1-8) were too limited in scope and detail to be useful." Therefore, the list of radionuclides that could contribute significantly to dose from the airborne plume was taken from more probable RSS fuel melt accidents and postulated design basis accident releases. The probability of exceeding inhalation PAGs at various distances from a reactor site during an accident is also provided. However, NUREG 0396 did not provide estimates of plume concentrations or whole body dose from individual radionuclides.

The list of radionuclides in NUREG-0396 is essentially in agreement with the evaluation presented in this document. The principle difference is that the NRC/EPA task force did not identify the strontium isotopes as being significant.

4.3.1 Comparison of Hazards

To evaluate the hazard from each radionuclide in the airborne plume, the projected dose was calculated for the organ receiving the highest dose per curie inhaled for the critical segment of the affected population. (Based on inhalation rate and body size, the teenager is the critical segment of the population for the inhalation pathway.) Source terms were taken from the RSS accident scenarios described above. The radionuclide plume concentrations were calculated using the assumptions in USNRC Regulatory Guides 1.3[46] and 1.4[47] and are presented in Appendix C, Table C-2. The projected doses were calculated using the inhalation model in USNRC Regulatory Guide 1.109[48] and are presented in Table C-3 of Appendix C. The assumptions used and a description of the model are given in Appendix C. Based on the evaluation in Appendix C (Page C-2), the teenager is identified as the segment of the population that will receive the highest dose. The results of the dose calculations for the two accident sequences are presented in Tables 3 and 4 as the ratio of projected dose to the PAG.

In the PWR-7 AHG-epsilon accident, the iodine isotopes result in a fraction of 1.97 of the 5 rem thyroid exposure inhalation PAG at 5 miles and a fraction of 0.65 at 10 miles. The Cs and Sr isotopes result in a fraction of 0.1 and 0.43 of the 1 rem whole body exposure PAG at five miles and a fraction of 0.03 and 0.15 at 10 miles, respectively. The dose from radioiodine exceeds the dose from particulate radionuclides in this accident as it does in most accident sequences (See Table 5). For the few accident sequences in which the release fraction of cesium is greater than the release fraction of iodine, the total release is less than the amount which might result in particulate inhalation doses greater than the PAG. This is demonstrated in the example BWR-5A accident, where doses from all radionuclides are less than 0.001 of the PAG at approximately 1 mile out from the reactor site.

Table 5. Comparison of Radionuclide Inhalation Doses from PWR-7 AGH-EPSILON Dose to Teenager in Rem if no Protective Action is Taken

Distance (miles)	I	Cs	Sr	Te	Ce	Ru
1	130	1.1E-1[a]	5.2	6.0	1.6	3.5
5	9.7	9.5E-2	4.3E-1	4.9E-1	1.1E-1	3.0E-1
10	3.2	3.2E-2	1.5E-1	1.7E-1	3.8E-2	1.0E-1

a 1.1E-1 = 0.11

4.4 Instrumentation Requirements and Alternatives

It is necessary to take air samples to determine the presence of radio-iodine and particulate radiation. Direct radiation measurements can determine the exposure from noble gases. Thus, both air sampling equipment and gamma exposure rate measuring instrumentation are essential for the Plume Exposure Rate Verification System. If an air sample for radio-iodine and particulates were taken (see Appendix D) and no significant amount of radioactivity were found on either the radioiodine or particulate filter, but measurable levels above background of gamma radiation were present, it would indicate one of three possible conditions:

a. Particulate radioactivity or radioiodines are not present in measurable quantities.

b. The measurements are being made just outside or beneath the plume (it is not located at ground level at that particular location).

c. The gamma measurements are being obtained from ground deposition and the plume is not at that location.

This information is important in determining projected dose. In the case of ground deposition, this can be determined by varying the height of the detector above the ground using open and closed window detector measurements, and observing variations in the instrument readings. This method can also be used to determine whether the instrument is beneath or off to the side of the plume. Measurements made after the plume has passed should have open window instrument readings which are significantly higher than the closed window readings if there has been deposition of particulate radioactivity or radioiodine, and both the open and closed window readings should increase as the detector position is varied from a height of one meter to ground level. If measurements are made in the plume, the open window readings should be significantly higher than the closed window readings, but there should be little change in either reading as the height of the instrument is varied from one meter to ground level. If the plume is above or off to the side of the instrument location but close enough to be detectable, both the open and closed window readings will be approximately the same because the instrument response will be due only to the detection of gamma radiation.[49]

If the plume is in contact with the ground at the points where air samples are taken, and measurements indicate little or no radioactivity on the particulate filters or air sample cartridges, then it can be safely assumed that significant quantities of particulates and radioiodine are not present in the plume. However, even if a plume containing particulates and radioiodine were elevated above the ground over a large area because of some unusual or peculiar meteorological conditions, and this was not detected, e.g., the air sample was not taken in the plume, the hazard at that location would be essentially the same as that from a plume composed of only noble gases. As long as these conditions persist, the only dose delivered would be the whole body dose due to gamma radiation from the plume. It should be noted here that the air sample cartridges must be taken to a low background area and purged with clean air before counting to obtain a proper measurement. (See Appendix D).

It is important that a monitoring system be composed of an instrument, or instruments, capable of measuring gamma radiation exposure rates up to approximately 100 R/h. The reason for having a high range instrument is that GM instruments designed only for measuring low exposure rates, e.g., tens of mR/h, may malfunction due to saturation of the GM detector under high exposure rates, e.g., tens of R/h. An instrument malfunction of this type may result in an instrument readout display which erroneously indicates no radiation exposure. The monitoring system should also have an air sampler with sampling media which can sufficiently discriminate among noble gases, radioiodines and particulates to permit evaluations of the measurements in the field with a gamma instrument which reads out in count rate or integrated counts over a fixed counting time interval. This monitoring system will be adequate to determine projected doses to the level required by the PAGs for a Plume Exposure Rate Verification System. Such an instrumentation package would consist of the following:

1. <u>Low-Range Gamma Survey Instruments</u> (range: approximately 0.1 to 50 mR/h)

1.1 CDV-700 or other GM survey instruments with moveable beta shields (see Appendix E).

1.2 NaI portable scintillation counters.

2. High-Range Gamma Survey Instruments (range: approximately 0.05 to 100 R/h)

2.1 CDV-715, or sealed ion chamber instruments (see Appendix E)

3. Airborne Radioiodine and Particulate Sampling System (sampling rate: 1 to 5 ft^3/min.)

3.1 Air sampler with adjustable flow rate.

3.2 Adsorbent filter media cartridges for collection of radio-iodine (silver zeolite, silver alumina or silver silica gel).

3.3 Particulate air filter.

3.4 DC power supply, DC to AC power converter or portable generator.

3.5 Count rate instrumentation

3.5.1 GM counter with a pancake type detector

3.5.2 Single channel or dual channel portable NaI scintillation counter.

Descriptions of the air sampling system are provided in Appendix D of this guidance. Specifications for the radiation survey and counting instruments and air samplers are given in Appendix E.

The instrumentation package should be used to verify the plume projected dose by traversing the plume while making both gamma only and beta plus gamma measurements. Beta plus gamma values significantly in excess of the gamma only values indicates the presence, at ground level, of the radioactive nuclides which are the constituents of the plume. When the presence of the plume at ground level is verified, air sampling is warranted at or near plume centerline. The air sampling time may be varied according to the plume exposure rate, i.e., higher exposure rate - shorter sampling time. However, care mast be exercised to not increase the required radioiodine detection level by taking too small of an air sample. Open and closed window measurements should be made by averaging the reading obtained over a 30-second time span for low exposure rates (10 mR/h) and over a 10-second time span for higher exposure rates at approximately 3 feet (1 meter) above the surface of the ground. An additional open and closed window reading should be obtained at a distance of approximately 3 inches (7.5 cm) above the ground at the same location. These readings should be recorded. The instrument detectors must be covered with a thin plastic material (such as a baggie) to protect the detector from becoming contaminated. The plastic covering must be thin enough to prevent significant attenuation of beta particle radiation.

After running the air sampler for approximately 5 minutes at 2 cubic feet per minute, the air sampler should be taken to a low background area. The sample filters should be purged with clean air prior to counting (as described in Appendix D). Remove the particulate filter from the filter holder and make a measurement of the count rate to determine the gross particulate radioactivity. Remove the filter medium cartridge and make a measurement of its gamma count rate. This is the reading for the gaseous radioiodine component (See Appendix D). The direct exposure background count rate measurement made at this sample counting location should be subtracted from the filter cartridge and particulate filter measurements. These field measurements should be reported immediately by radio for EOC evaluation. Both the particulate filter and the filter medium cartridge should be properly labeled, packaged to prevent cross contamination, and saved for a confirmatory evaluation using laboratory instruments for more accurate particulate and radioiodine measurements. After the initial assessment of thyroid dose commitment, based on the field measurements, laboratory measurements of radioiodine on both the particulate filter and the adsorbent medium cartridge should be made to verify the field measurements.

Emergency field monitoring for particulates in the airborne plume is very complex. The presence of particulates in the plume should not be ignored, although, their detection and measurement is of secondary importance compared to iodine. Rare accident scenarios can be devised where cesium and strontium release fractions would be higher than that of iodine. However, the amount released would result in comparatively lower doses. The options for monitoring particulates are: 1) gross counting of the particulate filter, 2) counting the particulate filter with a single channel analyzer, 3) counting the particulate filter in the field with a multi-channel analyzer, and 4) returning the particulate filter to a laboratory for analysis.

Gross counting of the particulate filter will not provide reliable information about the non-radioiodine particulate activity in the plume. A complex mixture of fission product radionuclides will be present on the filter, including some radioiodine. Since the exact fraction of iodine retained on the filter will not be known, the non-iodine particulate portion of the plume cannot be determined. Also, the particulate radioactive decay products of naturally occurring gaseous radionuclides, such as Rn-220 and Rn-222, will collect on the particulate filters and may interfere with field measurements of this type. In addition, a concentration of approximately one microcurie of each fission product radionuclide on the filter would be necessary to produce the PAG inhalation dose.

Determining the radionuclide composition on the particulate filter with a single channel analyzer would be very complicated and time consuming. The particulate filter may contain a complex mixture of radionuclides including fresh particulate fission products, several iodine isotopes and naturally occurring radionuclides, resulting in a complex spectrum of gamma ray energies, as well as pure beta emitters such as strontium-90. Since the gamma emitting radionuclides are identified by their respective gamma ray energy spectra, it would be difficult if not impossible to separate each gamma emitting radionuclide component from the entire gamma ray spectrum with a single channel analyzer.

The only practical means to establish concentration of particulates in the plume is to use multichannel analyzer counting equipment. This equipment is expensive and requires a laboratory and qualified personnel for proper operation.

A detector with multichannel analyzer and computer based spectrum stripping capability is essential for evaluating the particulate filter because of the complex energy spectrum resulting from the mixture of fresh fission products. These systems are best operated at a laboratory facility. Three types of detectors are used with the above instrumentation, NaI(Tl), Ge(Li), and intrinsic Ge. Due to the limitations on resolution of NaI(Tl) detectors, Ge(Li) or intrinsic Ge detectors should be used for fresh fission product measurements.

The most practical option for determining the noniodine particulate component of the plume is to return the particulate filter to a laboratory for analysis with a Ge(Li) or intrinsic Ge detector. It is important to emphasize the need for a quick turn around time between field collection and laboratory measurements. For planning purposes, field samples should be transported to a laboratory within approximately four hours of the time of collection. The information obtained from the laboratory measurements of the particulate air filters will be very useful to the decision makers during their process of verifying that the protective action recommendations made during the plume phase were valid, and for providing early information concerning the post plume phase portions of an accident sequence.

The evaluation of the particulate filter and adsorbent filter medium cartridge field readings should be made at the EOC or specified dose assessment location, as described in Appendix D, correcting for: 1) time between reactor shut down and the reading, 2) time between the start of the release and the reading, 3) iodine fraction on the particulate filter, 4) estimated plume immersion time if more than 2 hours, and 5) conversion of the iodine reading to projected dose to the child thyroid. These projected doses should then be used to convert the direct gamma measurements to projected dose at other locations at similar downwind distances. This use of direct gamma measurements should limit the number of air samples necessary to project the dose for each monitored location, because a simple ratio can be established between the direct exposure rate readings and radioiodine concentrations.

4.5 Survey Team Deployment

Portable, hand-held instrumentation as described for the above monitoring methods can best be deployed by monitoring teams in motorized vehicles. These teams should be directed to drive through the projected path of the airborne plume along appropriate routes and to take measurements at locations that can be identified from preselected reference points. The reference points for identifying measurement locations should be easily recognized places such as buildings, cross roads, street intersections, bridges, etc.[50] At the completion of the monitoring at each location and at the completion of the survey, the team will report the measurements obtained to the EOC where they can be plotted on a map of the area. The actual location of the plume and the concentrations of noble gases, radioiodines and airborne radioactive particulates within the plume will be determined, as will the projected radioiodine dose. These data should be compared against the projected exposure rate pattern, and appropriate adjustments should be made, keeping in mind that it is not unrealistic for the projected exposure rates to differ by a factor of a 100 or more from the measured exposure rates. Data from the facility, if available, should be factored into these projected exposure rate patterns whenever facility emergency plans include dispatching emergency monitoring teams.

The number of monitoring locations in a given area should be a function of the distance from the facility, the topography of the area, the density of population, and the presence of roads. All monitoring measurements should be made at approximately the same time and as quickly as possible. Therefore all monitoring teams should be deployed at approximately the same time and the length of time required for each team to cover its assigned survey route should also be similar. The frequency with which the plume should be surveyed is a function of the stability or consistency of the release and the local meteorology as well as the radioactivity concentrations and the number of people which may potentially be exposed. A more complete discussion of team deployment and the necessary logistics for such an operation are covered in Sections 6.5, 6.6, and 6.7 of this guidance.

4.6 Other Measurement Considerations

The FRPCC Subcommittee considered the concept of making field measurements of the distribution of radionuclide concentrations in the plume with a system of fixed monitoring locations as a method of estimating the dispersal of the plume and for projecting exposure patterns. This concept was rejected because of the large number of sophisticated detectors and the telemetry necessary for such a system. At least 150 detector locations would be required out to a distance of approximately 8 miles from the site for good spatial distribution.[51] Both radioiodine and direct gamma measurements would have to be made and telemeter to the EOC in order to get the necessary information for making a dose projection. The maintenance, repair and calibration of such systems would be very costly and hard to justify in view of the accident probability.

The deployment of instrumentation to make environmental measurements is partially dictated by the degree of instrument portability. For example, if the only instrumentation available for a specific measurement is a stationary system, such as a gamma spectrometer with a power source but without telemetry, then deployment must include periodic inspections to read out this system. Even if telemetry to the EOC is available, the system would probably require periodic servicing (i.e., changing filters, supplying gasoline, etc.). Conversely, if a choice of instrumentation exists, then the choice is influenced by the preferred deployment. For example, in choosing between stationary, mobile, or portable instrumentation, the desire for flexibility in choosing the measurement pattern should require the selection of portable instrumentation.

4.7 Cost Considerations

An important consideration for an emergency radiation monitoring plan is to minimize the cost because the probability for a nuclear accident large enough to produce significant offsite consequences at a specific facility is considered extremely small.[52] Further, for an actual accident, backup equipment will be available. The cost can be subdivided into three major categories: 1) the initial investment in equipment, 2) the cost of maintaining the equipment, and 3) the cost of training and retraining personnel. The State should minimize its investment in equipment that is operated solely for accident monitoring. However, that equipment purchased should be reliable. This will reduce maintenance costs. Instrumentation from other activities such as civil defense should be used where possible.

The developer of State emergency radiation monitoring plans should first determine the deployment of available stationary instrumentation around the facility that may satisfy the requirements for a time history of measurements at selected spots in the measurement pattern. The facility itself may have a number of offsite measuring systems, normally used for environmental monitoring purposes, which also have an emergency measurement capability. The State planner should then ascertain the portable instrumentation that is available from local units for use by survey teams in a more flexible measurement pattern. Available resources in the locality should be compared to the total resources needed for the State plan. Additional instruments may be made available through the Federal government as described in Appendix D. The State should acquire the remaining instrumentation needed to complement these resources.

Portable instrumentation is expected to be the most cost-effective category of instrumentation for measuring exposure rate patterns from an airborne release from a nuclear accident. The plume from such a release may cover a large area and its shape may be continuously changing with the prevailing meteorology. Therefore, a flexible system using a limited number of measuring devices is much more cost effective than the large number of fixed detectors with their associated telemetry required to obtain the same information.[53]

4.8 Incident Time History Instrumentation

Stationary, continuously recording instrumentation maintained offsite solely for the purpose of obtaining a time history of the exposure rates from a nuclear incident is not cost-effective. However, if stationary, continuous monitoring instrumentation is maintained for other purposes, i.e., environmental monitoring, it may be easily modified and made available at a small additional cost for recording a time history of the exposure rates from the plume.

Fixed instrumentation (or instrumentation that is already in place at specific sites) that may be moved to a specific site can also be used to continuously record the time history of the exposure rate. An example of deployable instrumentation would be a continuous air sampler and/or a gamma radiation rate meter with a recorder and its own portable power supply. This system could be mounted on a stand, carried to a location by truck and set up in the field to make continuous measurements. The disadvantage of deployable instrumentation of this type is that it may miss the onset of the release. However, this disadvantage is offset by lower maintenance costs and more control over the sitting of the instrumentation in the plume compared to a stationary instrumentation system. The preceding remarks on the cost effectiveness of stationary instrumentation also apply to deployable instrumentation.

An application for a time history of the exposure rates from the plume is to follow the course of the accident and to assess the offsite consequences over the length of the release. Most facilities maintain some stationary and/or moveable instrumentation for assessing the offsite consequences for both routine and accidental releases. If time history data is needed for protective action decision making, for example, during a very prolonged release, the State should plan to obtain this data from the facility and the Federal support teams (FRMAP) who should have the necessary instrumentation.

4.9 Aerial Radiological Monitoring

Ground-level exposure rates from an airborne release cannot be deduced accurately from aerial measurements made above the radioactive cloud. Radioiodine and radioactive particulate concentration in air measurements are difficult to make from an airborne platform without contaminating the aircraft. Consequently, aerial measurements of the radioactive cloud have little value for determining ground level exposure rates from an airborne release. However, an aerial monitoring capability is useful for observing the direction and extent of the airborne plume, i.e., tracking the cloud. The Aerial Measuring Systems (AMS) program of DOE is expected to be available within 12 hours or less after the start of a nuclear accident for tracking the cloud and for making other measurements. During these first 12 hours, the EOC Director may need an aerial cloud tracking capability to complement the ground-based survey team for certain meteorological and/or site conditions. For example, if the release is over terrain inaccessible to survey teams or if the wind shear conditions are such that the movement of the upper part of the cloud is different from the lower part of the cloud, then a cloud tracking capability may be a valuable complement to the survey team capability.

The AMS is potentially very useful in defining the boundaries of the contaminated area, especially if a large contaminated area is expected. AMS may utilize either helicopters or fixed-wing aircraft which are equipped with a detector array having twenty 5" x 2" NaI(Tl) scintillation crystals which are equally distributed within two cargo pods.[54] This system is effective for detecting and identifying gamma emitting radionuclides which have energies greater than 50 keV. The helicopter mounted detector system has a sensitivity range of less than 0.1 to 1.0

μCi/m² for gamma energies greater than 50 keV. The fixed-wing aircraft detector system has a sensitivity ranging from 1.0 to 10 μCi/m² for similar gamma energies.[55] However, at gamma energies between 50 and 100 keV, the detection limit is highly dependent on the geometry of the source and its distribution in the soil. The difference in sensitivity between these two aerial systems is due to the helicopter's ability to be flown at lower altitudes and at lower air speed than the fixed wing aircraft.

The normal data output from AMS is in units of microroentgens per hour extrapolated to one meter above ground level.[56] The data from the aerial radiological survey is recorded on magnetic tapes for further data reduction using a ground based computer system.

Generally, aerial radiological surveys are capable of: 1) detecting areas of enhanced radiation, 2) determining the average surface area exposure rate, and 3) identifying the specific radionuclide(s) responsible for any observable anomaly.[57] However, this system has the following limitations: 1) it may be grounded by inclement weather conditions either at the home air base or at the accident site, 2) it can only detect gamma emitting radionuclides, 3) it is unable to distinguish between contamination on crops and contamination on the ground, 4) it is of little or no value for detecting waterborne releases, and 5) it may underestimate the magnitude of localized sources, since aerial detection systems tend to average gamma exposure rates over a large area.

An aerial radiological monitoring capability has been developed by FEMA for use by the States using Civil Air Patrol and other volunteer civil aviation groups. These aircraft and personnel, if located within an hour's flying time from the nuclear site and equipped with properly sensitive instrumentation, can fill this interim plume tracking need. Special training of the volunteer pilots and observers is required. The pilots should be instructed to fly above the plume, e.g., about 3,000 to 5,000 feet above the ground, to avoid contaminating the aircraft, and along predetermined flight paths using visual navigation points. The CDV-781 Aerial Radiological Survey Meters must be replaced with a more sensitive gamma survey meter which can be carried within the aircraft and visually observed. A 0-50 mR per hour GM or scintillation survey meter (Section 4.3, "Low-Range Gamma Survey Instruments") should be adequate for this purpose. Observations should be reported by radio directly to the EOC or to a radio-telephone relay point.

The greatest value of an aerial radiological monitoring capability is for aerial surveys of deposited materials after the airborne release has dissipated. The AMS Program is designed for these purposes, and the State agency should plan to utilize this Federal capability (Appendix A).

5 EMERGENCY WORKER RADIATION EXPOSURE MONITORING SYSTEM

An emergency worker is an individual who has an essential mission within the Plume Exposure EPZ to protect the health and safety of the public who could be exposed to ionizing radiation from the plume or its deposition. The emergency worker must be trained in the basic characteristics of ionizing radiation and its health effects. The individual must be able to determine his cumulative radiation exposure with a direct reading dosimeter and know what to do when exposure limits and turn-back[a] values are reached while carrying out his mission to protect the health and safety of the public within the plume exposure EPZ.

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[a] Turn-back values are total accumulated external exposure limits or exposure rates, established by the offsite health authority, at which the emergency worker should immediately leave the

Emergency workers include the following: radiation monitoring team personnel; transportation services (evacuation vehicle/bus drivers); law enforcement, fire fighting, and rescue personnel, including ambulance crews; personnel carrying out backup route alerting procedures; traffic control personnel; emergency operating center personnel; same personnel at institutional, health service, or industrial facilities, and some essential services or utility personnel (electric, gas, water, water treatment, telephone, etc.). These personnel are considered emergency workers only when their services are required to protect the health and safety of the general public during the emergency phase of an accident.

Emergency workers, such as radiation monitors, police, firemen, rescue personnel, ambulance crews, evacuation vehicle/bus drivers, and personnel carrying out backup route alerting or traffic control functions may be exposed to the airborne release while carrying out their missions.

Consequently, the means for measuring the radiation exposure of these personnel must be available at the beginning of the nuclear accident.

The objective of the emergency worker radiation exposure monitoring system is to minimize the exposure of emergency workers to radiation from the accident and to measure their accrued exposure. Three categories of data are needed for emergency worker exposure mission planning.

These categories are:

1. Projected exposure rate patterns for planning purposes,
2. Survey measurements to estimate radiation exposure at specific assigned emergency worker locations within the plume EPZ, and
3. Personal dosimetry to measure accrued radiation exposure.

The primary radiation exposures of concern to emergency workers are: 1) whole body external exposure to gamma radiation from airborne particulates, gases, and particulate radioactivity deposited on or near the ground and 2) internal exposure to the thyroid from the inhalation of radioiodines. Consequently, dosimetry for external beta radiation is not required.

The PAGs[58] for emergency workers are:

Category	Whole Body Exposure	Thyroid Exposure
Emergency Workers	25 rem	125 rem
Lifesaving Missions	75 rem	No limit

5.1 Projected Exposure Rate Patterns for Planning Purposes

Whenever emergency personnel are planning to undertake an operation, it is essential that the best estimate of the situation be known by the personnel directly involved. All sources of information, including projected exposure rate patterns, should be considered and a best estimate made of the exposure likely to be received during a specific mission. The mission must be planned by taking into consideration the most likely situation as well as the most potentially

radiation area without further consultation or direction. Continuation of an emergency assignment at radiation exposure rates or accumulated radiation exposures above these turn-back values should be authorized by the cognizant health authority and only for justifiable reasons. For example, an integrated exposure of 5 rem per mission assignment or 5 R/h exposure rate.

hazardous situation. Items to be considered include alternative entry and exit routes, potential changes in meteorological conditions, areas or roads to be avoided, equipment: and vehicle failure, and other relevant items.

5.2 Exposure Rate Survey Measurements at Specific Emergency Locations

Radiation surveys of the exposure rates at all emergency locations where operations will be conducted are necessary in order to determine the amount of time available to workers for carrying out their emergency assignments.

Two types of measurements are required:

1. Gamma radiation exposure rate measurements.

   Low-range and high-range survey meters are required that can measure the gamma exposure rate from 0.1 mR/h to 100 K/h, as discussed in Section 4 for plume exposure rate verification.

2. Radioiodine concentration measurements.

   The airborne radioiodine concentration should be measured to estimate the thyroid dose commitment. This measurement requires an air sampler with an iodine absorber cartridge and a detection instrument. The equipment needed and a method for making this measurement are described in Appendix D.

Emergency workers on the monitoring teams involved in the plume exposure rate verification mast have the necessary equipment and instrumentation to conduct the measurements described in both Items 1 and 2 on the preceding page. Emergency workers assigned to non-plume exposure rate verification activities, such as route alerting or driving evacuation buses, should rely on their direct reading dosimeters as a means of monitoring their exposure. However, it would be desirable for those individuals assigned to access control points, e.g., special traffic control points established to prevent unauthorized access to evacuated areas, and fire and rescue personnel, including ambulance crews, to be equipped with one of the survey meters indicated in Item 1 on the preceding page.

5.3 Measurement of External Gamma Radiation Exposure

Personal dosimetry should be provided to all personnel involved in emergency operations in any area where significant radiation exposures may be possible. Such dosimetry will provide data to the individual to control his/her exposure to gamma radiation while completing the mission assignment and to the organization's administrative records department to quickly document any significant radiation exposure to the worker. The major dosimetry systems[59] that should be considered as alternatives are:

1. Direct or self-reading ionization chamber (pocket) dosimeters,
2. Indirect or non self-reading ionization chamber (pocket) dosimeters,
3. Thermoluminescent dosimetry (TLD) systems,
4. Film badge systems, and
5. Combinations of systems, e.g., TLD plus direct reading dosimeters.

From the radiological emergency standpoint, direct reading ionization chamber dosimeters are clearly the best system for measuring whole body gamma exposure for personnel and providing a continuous indication of the amount of the radiation exposure. The reasons for the recommendation of these devices include the following:

1. A cumulative exposure for each individual can be read at any time or location without the need for ancillary equipment,
2. They can be used repeatedly by simply recharging,
3. They have a long shelf life with little to no maintenance requirements,
4. The individual can directly read his/her exposure,
5. They measure gamma exposure accurately and are reasonably energy independent from 70 keV to 2 MeV, and
6. They are hermetically sealed at the time of manufacture and are relatively insensitive to environmental conditions.

The disadvantages to the use of the direct reading ion chamber dosimeter include the following:

1. No permanent record of the exposure is possible except by manually recording the exposure readings,
2. The exposure readings on the devices may be sensitive to a significant mechanical shock, e.g., if dropped more than a few feet to a concrete surface, and
3. The initial cost is high.

Direct reading ionization chamber dosimeters are clearly the most desirable option, because the primary requirement for personal dosimetry for emergency workers is that an individual be able to read his/her exposure at any time to prevent the accumulation of excessive dose. Large quantities of dosimeters of this type have been used satisfactorily for years by industrial workers, civil defense personnel, and the military. However, the users of the direct reading dosimeters must have assurance that the dosimeters are capable of meeting the criteria of Standard N322-1977 of the American National Standards Institute.

5.4 Dosimetrv Systems for Use During an Emergency

Direct reading personal dosimetry that accurately measures whole body gamma radiation exposure is necessary for all personnel who will be working within or return to work within the plume exposure EPZ. If an individual is required to comply with State, local, or facility administrative exposure limits which are lower than the emergency worker PAGs specified by the EPA, the parent organization of the personnel should provide these individuals with additional direct reading dosimeters capable of measuring the administrative exposure limits. However, low-range direct reading dosimeters (less than 0-5 R full scale) are not an appropriate range for use during an emergency accident at a nuclear power plant. If direct reading dosimeters with a full scale reading of less than 5 R are used, they should be used only by individuals who use these routinely every day (under NRC or State byproduct material licensed activities) and in conjunction with one or more higher range direct reading dosimeters. The provisions for their limited use should be documented with the parent organization during the formulation of the State radiological emergency preparedness plans.

All emergency workers should be provided with a film badge or preferable a thermo luminescent dosimeter (TLD) as well as at least one direct reading dosimeter, e.g., a 0-20 R or a 0-5 R dosimeter for the most reasonably expected preplanned exposures in conjunction with a 0-200 R dosimeter for possible accidental exposures that might be received in excess of the range of the 0-5 R dosimeter. The TTDs will measure whole body gamma radiation exposure for the following purposes:

1. Provide a measurement of the total accrued exposure during the duration of the accident,
2. Provide redundant measurements and more accurate measurements to the direct reading dosimeters if the dosimeters are lost or their reading is destroyed,
3. Provide documentation of an accrued exposure of less than the minimum amount that can be read on the direct reading dosimeter and which, therefore, cannot be measured accurately (approximately 1% of the full scale value of the direct reading dosimeter, i.e. 0.05 R on the 0-5 R dosimeter and 0.2 R on the 0-20 R dosimeter),
4. Provide accidental exposure readings that are beyond the range of the 0-200 R direct reading dosimeter, and
5. Provide a legal documented record of an individual's accrued exposure during the duration of the accident.

The TLD could be incorporated into an exposure record information card. This information card could be issued to each individual as they report for mission assignments. The card would be completed by the worker giving his/her name, organization, social security number, and other desired information. This information card could then serve as a means of determining the personnel assigned to the emergency work force and to provide the information needed for documenting individual exposure records. The TLD contained in each identification card should be collected and read approximately every thirty days or after the accident conditions have been mitigated, which ever is the lesser, to confirm the total integrated exposure of each individual during the accident.

In order to reduce the cost, provision could be made by the State to use a TLD which is compatible, with an existing TLD reader available within about 24 hours from the start of the release. The TLD's should be calibrated and annealed at least once each year against this reader so that they are ready for distribution in case of an emergency. A preferable alternative to this TLD system would be to use a commercial TLD service. While a film badge service would be acceptable, a film badge is not nearly as good as a TLD.

In view of the previous discussion, the FRPCC Subcommittee has established both a Recommended System and a Minimum Acceptable System for emergency worker dosimetry. These emergency worker dosimetry systems are defined as follows:

1. Recommended System: Two direct reading dosimeters with different ranges that can adequately cover a range of radiation exposure from 0.5 R to 100 R. One dosimeter with the ability to measure radiation exposures as low as 0.5 R and up to at least 5 R, but no more than 20 R. A second dosimeter with the ability to measure exposures from 5 R up to at least 100 R. The two direct reading dosimeters should, as a minimum, meet the American National Standards Institute (ANSI) Standard N322-1977, Inspection and Test Specification for Direct and Indirect Reading Quartz Fiber Pocket Dosimeters,[26] and be certified. The dosimeters must be annually recharged, tested for electrical leakage, and calibrated for radiation accuracy. The lover range

direct reading dosimeter allows the emergency workers to monitor their radiation exposures for turnback values. The higher range dosimeter allows the emergency worker to immediately read any exposure received above the full scale reading of the lower range dosimeter and also to measure exposures up to and even above 75 rem which is the EPA's lifesaving PAG for emergency workers. The reasons for recommending an upper limit of 100 R is that there are many direct reading dosimeters available which cover this range, e.g., a 0-100 R CD V-730 or a 0-200 R CD V-742, and they have adequate sensitivity to measure exposures of as little as approximately 1 R and 2 R, respectively.

In addition, a permanent record dosimeter consisting of a film badge or preferable a multiple chip TLD as a backup device for the direct reading dosimeters and to provide a permanent individual administrative record. The TLD or film badge should be read by a processor appropriately accredited by the National Voluntary Laboratory Accreditation Program (NVLAP) in accordance with ANSI Standard N13.11-1983, Personal Dosimetry Performance -Criteria for Testing27 (see Appendix E). NVLAP accreditation must be for the specific type of dosimetry in use, and must be for the type of radiation for which the individual wearing the dosimeter is being monitored.

2. Minimum Acceptable System: One direct reading dosimeter with a range capable of measuring a radiation exposure of at least 20 R and a minimum exposure of 0.5 R. If one direct reading dosimeter covering this range of sensitivity is not available, then two direct reading dosimeters which meet the range criteria of the Recommended System described above should be used. The dosimeter(s) must be certified, annually recharged, leak tested and calibrated, and meet ANSI Standard N322-1977.

In addition, a permanent record dosimeter consisting of a film badge or preferable a multiple chip TLD as a backup device for the direct reading dosimeter and to provide a permanent individual administrative record. The TLD or film badge should be read by a processor appropriately accredited by the NVLAP in accordance with ANSI Standard N13.11-1983, Personal Dosimetry Performance - Criteria for Testing[60] (see Appendix E). NVLAP accreditation must be for the specific type of dosimetry in use and must be for the type of radiation for which the individual wearing the dosimeter is being monitored.

Low-range (less than 0-5 R full scale) dosimeters are inadequate for emergency workers during the emergency phase of a radiological accident. The FRPCC Subcommittee recognizes that the as low as reasonably achievable (ALARA) principle should be applied where possible. However, the very nature of this type of emergency may necessitate that a small number of emergency workers incur significant radiation exposure in order to reduce the overall radiation exposure of the general public.

Individuals who might come in contact with radioactive materials during the emergency as a result of the accident and whose emergency job assignments are outside the plume EPZ should be considered radiation workers. For example, those personnel responsible for environmental sampling, radiological monitoring and radiological record keeping at emergency worker or evacuee monitoring centers, decontamination centers, traffic and access control points, medical services or hospitals, provided they are located outside the plume EPZ, are considered to be radiation workers. Exposure limits allowed for these individuals should be the same as those allowed for a radiation worker for occupational radiation exposure, i.e., up to five rem for the duration of the emergency. These personnel are also required to have appropriate dosimetry (a permanent record dosimeter and at least one direct reading dosimeter) to monitor an individual's radiation exposure. Dosimetry requirements for all anticipated radiation workers must be specified in the emergency response plans and operating procedures. Since these personnel are considered to be radiation workers, they must also be trained in the basics of radiation protection and radiation safety. (Note: For those hospitals which are under contract to the utility to provide medical services to onsite personnel, emergency worker dosimetry requirements must be met regardless of the location of the facility to the plume EPZ.)

Personnel without public health and safety missions, such as farmers for animal care, other agribusinesses, environmental/agricultural sampling team members, essential service personnel, or other members of the public who must reenter a restricted radiation area following the plume passage and delineation of the restricted area, should be limited to the occupational radiation worker exposure limit rather than the emergency worker exposure limit. Each individual should be provided a permanent record dosimeter capable of monitoring the radiation worker's exposure limit up to five rem for the duration of the emergency and at least one direct reading dosimeter capable of monitoring the radiation worker's exposure limit for each assigned mission.

The range of the direct reading dosimeters used for measuring the radiation exposure of radiation workers should be determined by the State. If a dosimeter is assigned to an individual for the duration of the emergency/ ranges of 0-1 R through 0-5 R would be appropriate and would minimize the need to have the dosimeter frequently rezeroed, would still provide the measurement accuracy needed, and would read in the same units (R) as those used for emergency workers which would contribute to less confusion and reading error. However, a 0-1 R dosimeter, or even a dosimeter with a range as low as 0-200 mR could be used if dosimeters are collected and read after each mission. Problems that State and local governments must be aware of is that direct reading dosimeters with a full scale range of less than 1 R are much more difficult to rezero; exhibit much more geotropism (error in reading); are extremely likely to exhibit erratic electrical leakage, especially if they are not used on a continuous daily basis and routinely charged on the same charger; should be recharged on a special charger which grounds the center electrode charging pin and decreases the amount of electrical leakage; and are much more susceptible to high or totally lost readings if dropped onto a hard surface from a distance of more than 2 or 3 feet. The civil defense CD V-138 0-200 mR dosimeter exhibits the above problems, except for the loss of reading due to being dropped. It is <u>not recommended</u> that radiation workers use the CD V-138 dosimeter for operational purposes for emergency response.

Great precision in the ability to read the direct reading dosimeter is <u>not</u> required, since this device <u>primarily</u> provides an immediate indication of the general amount of radiation exposure received. The legal record of a worker's radiation exposure will be determined from the processed TLD or film badge. Further, during the recovery/reentry phase of an accident sequence, an individual may be exposed to low exposure rates for a mere prolonged period of time. Under these conditions, the direct reading dosimeters recommended for the emergency worker may not be sensitive enough to provide an accurate indication of the individual's daily accumulated exposure, although any significant daily exposure, e.g., approximately 200 mR, will be able to be read on a 0-20 R dosimeter and approximately 50 mR on a 0-5 R dosimeter.

Therefore, the FRPCC Subcommittee recommends that all individuals rely upon their permanent record TTD dosimeters to provide a record with more accuracy of exposure accrued during all phases of the accident. If individuals encounter significant ground deposition hot spots (exposure rates greater than 100 mR/h) during the recovery/reentry phase, they would be adequately monitored by the proper use of the direct reading 0-5 R or 0-20 R dosimeter, as well as by the measurements indicated by their radiation survey instruments.

5.5 Other Dosimetric Devices

In addition to the principal types of dosimeters given above, there are pocket size devices usually referred to as "alarming dosimeters" or "personal radiation monitors." These devices are small transistorized, battery operated radiation detection instruments which usually use a small halogen quenched Geiger Mueller (GM) tube as the detector. The GM detector triggers an audio tone which rises in frequency as the exposure rate increases, or provides a periodic signal or "chirp" which is produced more rapidly with increasing radiation exposure rate. Other devices of this type provide a light emitting diode (LED) or liquid crystal display (LCD) readout which gives the integrated exposure measurement over the period of time that the instrument is operated. However, except for those devices that provide an actual integrated exposure reading, direct reading dosimeters should also be used with these instruments. Possible pitfalls in the use of the GM detectors for dosimetry application are:

1. The spectral gamma response problems inherent with GM detectors, if not properly calibrated and compensated,
2. An upper limit of detection of around 20 R/h or an integrating capacity of 5 R total exposure, which may not be adequate, and
3. Many of these devices have a non-linear response at high exposure rates due to the non-linear pulse rate and loss of pulse height by the GM tube with increasing radiation flux.

In addition, the cost of these devices is approximately four times the price of a direct reading dosimeter. Therefore, the purchase of these instruments specifically for use by emergency workers is not recommended. However, if instrumentation of this type is already available, it can provide a useful adjunct to the recommended dosimetry system for monitoring teams and emergency workers.

5.6 Thyroid Dose Commitment from Iodine Inhalation

Thyroid dose from the inhalation of radioiodine is likely to be a significant problem in reactor accidents. Therefore, in addition to gamma radiation dosimetry, personnel involved in emergency operations who are exposed to the airborne release can be provided with protection of the thyroid from radioiodine. The dose to the thyroid of an emergency worker from iodine inhalation may be minimized by instructing emergency personnel to take stable iodine orally, in the form of potassium iodide tablets or liquid drops, in order to block the uptake of any significant amount of radioiodine as described in the EPA Manual1 and NCRP Report No. 55.28 The FRPCC has developed a Federal policy on the distribution of potassium iodide around nuclear power plant sites for use as a thyroidal blocking agent.[61]

The Food and Drug Administration[62] (FDA) has stated that the administration of 100 mg of iodide (130 mg of potassium iodide) prior to radioiodine exposure results in blocking over 90 percent of the peak radioactive iodine uptake in the thyroid.[63] A block of up to 50 percent is attainable if the dose is given within 3-4 hours after acute exposure and some benefit is obtained even if the drug is administered up to 12 hours after exposure.

A daily dose of potassium iodide would be required to maintain the blocked state and should be continued 3 to 7 days to prevent thyroidal uptake of any radioiodine still circulating in the body. Use is not expected to exceed 10 days. All emergency workers should be medically checked for sensitivity to potassium iodide to assure that there will be no undesirable medical effects.

Respiratory protection equipment, half and full-face charcoal filtered masks, and particularly air-supplied masks, could be used, if available, to reduce the inhalation dose to the thyroid. However, the use of potassium iodide is a much more effective procedure for reducing thyroid dose. If respiratory, protection equipment is to be used by emergency response personnel, each individual wearing the respiratory protection equipment must be qualitatively fit tested in accordance with ANSI Z88.2-1980[64] and the individual must meet the physical qualifications specified in ANSI Z88.6-1984.[65]

Thyroid dose can be estimated with a fair degree of accuracy by measurement with a gamma radiation detector held horizontally adjacent to an individual's thyroid, which is immediately below the Adam's apple. From the count rate obtained, an approximation of the thyroid uptake can be obtained from data given in Table 6.[66] The data presented in Table 6 are averages of ten measurements made on thyroid phantoms. Each instrument's detector was positioned to give maximum responses, i.e., horizontally adjacent to the neck, with the detector's active area centered between the thyroid lobes. From the above data, the projected dose to the thyroid from either a single or continuous uptake of radioiodine can be obtained using the following equation:

$$ {}^{D}Th = {}^{k}D \times \mu $$

where ${}^{D}Th$ = projected thyroid dose in rem
${}^{k}D$ = dose conversion factor in rem/microcurie in the thyroid
μ = uptake in microcuries

Table 6. Detector Response for Thyroid Models[a] (Net cpm per microcurie ^{131}I in thyroid)

See attached image – Table 6

where ^{D}Th = projected thyroid dose in rem
^{k}D = dose conversion factor in rem/microcurie in the thyroid
μ = uptake in microcuries

The dose conversion factors (^{k}D) for human thyroids are 6.50, 19.1, and 36.0 rem/microcuries ^{131}I uptake for adults, 5 year olds, and two year olds, respectively.[67] the dose conversion factor for the two year old was estimated from Figure 3, which is a plot of dose conversion factors versus the midpoints of the infant, child, teenager, and adult age groups.

The sensitivity of this monitoring method can be determined by calculating the minimum detectable levels (MDL) for the monitoring instruments. The MDL is a function of the uncertainty of instrument backgrounds and as such it will vary among instrument types as well as within an individual instrument based on the sample measurement location, e.g., potentially different backgrounds for different locations. For instruments with analog readouts, the MDL in counts per minute can be calculated from the equation:

$$MDL= 2 \sqrt{B/2RC}$$

where B = background count rate in counts per minute
RC = meter time constant in minutes, which can be determined from information normally found in the manufacturer's specifications

For instruments with digital readouts, the MDL can be expressed by the equation:

$$MDL = 2 \sqrt{B}$$

where B = background count rate in counts per minute instruments and the different human thyroid models.[b] The 2 year old child has the highest minimum detectable dose commitment because the dose conversion factor for the child is the largest, i.e., requires fewer counts per minute per rem dose commitment. This is because the thyroid of the child is the largest as compared to body weight.

Figure 3. Dose Conversion Factors in rem/ci Uptake in the Thyroid vs. Age in Years

See attachment for image – Figure 3 and Table 7

Table 7. Minimum Detectable Levels – CPM[a]

See attached image – Figure 3 and Table 7

[b] The minimum detectable dose commitment values found in Table 8 of this document are different from the values contained in Table 7 of Reference 31, because the dose conversion factors used in Reference 31 are incorrect, e.g., dose conversion factors for radioactivity inhaled into the body were used rather than dose conversion factors for radioactivity contained in the thyroid.

Table 8. Minimum Detectable Dose Commitment for Thyroids[a,b] REM Infinity [c]

See attachment for image – Table 8

Scintillation detectors have the most sensitive detection level for ^{131}I in human thyroids. The 5 x 5 cm (2x2 in.) Nal(Tl) crystal detector is able to detect radioactivity levels approximately equivalent to a 0.03 rem dose commitment for two year olds under the test background conditions. The smaller 3.2 x 3.8 cm (1.25 x 1.5 in.) Nal(Tl) crystal detector is able to detect radioactivity levels equivalent to a 0.14 rem dose commitment for two year olds. The GM detectors are less sensitive than the scintillation detectors. The least sensitive of the GM detectors tested is able to detect radioactivity levels equivalent to a 4.3 rem dose commitment for two year olds.

This thyroid monitoring procedure is recommended only for screening all emergency personnel at the completion of their final mission involving direct exposure to the plume or evacuees who are known to have been exposed to the plunge for a significant period of time prior to evacuation (see footnote (b) to Table 8). If this procedure indicates a projected dose of more than 10 rem to the thyroid, the individual should be sent to a hospital or laboratory where an accurate determination of the radio-iodine uptake can be made. Ten rem to the adult thyroid would result in a reading of approximately 1200 cpm on the CD V-700 with a standard D-103 detector, i.e., just a little more than 1/3 of full scale on the Xl range.

The minimum detectable dose commitment values found in Table 8 of this document are different from the values contained in Table 7 of Reference 31, because the dose conversion factors used in Reference 31 are incorrect, e.g., dose conversion factors for radioactivity inhaled into the body were used rather than dose conversion factors for radioactivity contained in the thyroid.

5.7 Post Accident Considerations

Following participation in an accident where significant contamination has resulted, as indicated by projected doses, field measurements, or personal dosimetry, those potentially exposed emergency workers should be scheduled for and given a routine examination for internally deposited radioactive contamination. This is in addition to the thyroid monitoring described in Section 5.6 above. This is a procedure which should be performed using standard health physics techniques and could be conducted at a mobile laboratory van or in a local hospital. As a minimum, the examination should include the taking of both fecal and urine samples for analyses.

In the event that initial sampling indicates any internal exposure, whole-body counting at a special facility and further sampling should be instituted. This information should be well documented as discussed in Section 6.1 and coordinated with contamination control activities discussed in Section 6.4.

6 OTHER CONSIDERATIONS FOR OFFSITE RADIATION MEASUREMENT SYSTEMS

6.1 Documentation

After the emergency phases of a nuclear incident are over, there will be many studies and investigations directed towards:

A. Assessing the impact of the incident, and

B. Measuring the effectiveness of the State radiological emergency preparedness plan for use in improving future plans.

Both of these efforts will involve reconstructing the incident based on the available data, and both efforts will also involve calculations of the dose received and the dose saved by implementation of protective measures. Some of the post-accident investigations may require that data be introduced as evidence at legal proceedings. Consequently, it is important that data be documented with these aspects in mind. All measurements should be fully documented; i.e., date, time, location, weather conditions, measurement readings, background readings, instrumentation identification number, transfer of data and samples, signatures of personnel and witnesses to the signatures, and other pertinent information in order that they may be used for assessment purposes.

All State radiological emergency preparedness plans, including plans for emergency radiation monitoring, should be reviewed for proper documentation. Accordingly, preprinted forms with specific directions should be developed for documenting appropriate actions.

6.2 Quality Assurance

The instrumentation used to measure personnel exposure, exposure rates from direct external radiation, or levels of radioactivity in various types of samples, should have a high degree of reliability. The accuracy of the instrumentation calibration should be within ± 10% with a confidence level of 95%. The secondary radiation calibration standards used to perform these calibrations should have an accuracy within ± 5% of the true value and should be calibrated against a measurement standard traceable to the National Bureau of Standards. The calibration of these standards should be periodically revalidated.

The frequency of calibration required for various types and models of instrumentation varies with their known degree of calibration stability. This frequency should be determined for each type and model of instrumentation by comparison with past calibration data and should also be based on the recommendation of the instrument supplier in accordance with the guidance in NUREG-0654 Planning Standard and Evaluation Criteria H.10.[68] The amount of change in radiation sensitivity detected between previous calibrations and the period of time over which these changes occur could determine the future calibration cycle.

In general, ionization chamber dosimeters and high-range survey meters show little or no change in sensitivity unless they became defective. Calibration checks of these types of devices are performed more to detect defective units than to determine sensitivity changes. The calibration frequency for such civil defense devices used for civil defense purposes is once every four years. However, civil defense instruments which are used for radiological emergency response (REP) purposes must be calibrated at least annually and this frequency should be designated in the procedures section of the State or local emergency response plan. Instrument calibrations should conform to ANSI N323-1978, Section 4.[69] GM type exposure rate measuring instruments, TLD's or other instruments utilizing more sophisticated electronic circuits should be calibrated more often, since slight changes in component characteristics can often significantly change their ionizing radiation response. Generally, instruments using vacuum tubes require the most frequent calibration. However, there are many exceptions to this rule.

Any time electronic components or detection devices are repaired or replaced, the instrument should be recalibrated. Instruments which exhibit battery voltage sensitivity should be calibrated every time the batteries are changed (See ANSI N323-1978, Section 3).

Thermoluminescent dosimeters have to be annealed, i.e., heated at a manufacturer's specified temperature, after each readout to remove any residual absorbed energy from exposure to radiation. Uniform annealing heating rates and post annealing cooling rates produce TLDs of uniform sensitivity. The TLDs should be calibrated after each annealing by exposing randomly selected TLDs to a radiation source for varying periods of time. The radiation source should be similar in energy to the radiation expected to be measured by the TLDs under field conditions. This radiation calibration source should be periodically tested with a secondary standard, i.e., calibrated ion chamber, to determine its exposure rate. The output reading of each TLD exposed to the calibration source should be plotted against its total accumulated exposure to produce a calibration curve of TLD output response versus accumulated exposure.

For radiation detection instruments other than TLDs, calibration history is by far the best means of determining an instrument's calibration frequency, and rule-of-thumb should only be used until such a history is established. It is therefore necessary to document and preserve calibration data.

Calibration of all instrumentation should be performed to establish linearity of radiation response as well as accuracy. However, once this linearity is determined in ion chamber type dosimeters and instruments, a one point calibration will suffice since these characteristics rarely change in these types of devices. Other types of exposure rate measuring instrumentation, particularly instruments using GM detectors, generally exhibit non-linear response. Since non-linearity can shift with changes in electronic components, more than a one point calibration should be made. In the case of GM instruments, or instruments with logarithmic and semi-logarithmic response, a calibration response curve based on several points across the meter scale, or over the range of sensitivity, should be provided with each instrument. A calibrator traceable to NBS is available in most States for the calibration of CDV-700 survey meters.

If the instrumentation is not used on a regular basis, periodic operability checks must be made. For exposure rate measuring devices, this check must determine whether the instrument is capable of accurately measuring the radiation level of an appropriate check source, or at least, that the power supply is in operating condition. In the case of ion chamber type dosimetric devices, a check for leakage of the ion chamber must be made. Thermoluminescent dosimeters should be periodically annealed to assure an up-to-date background level.

The minimum calibration and battery replacement frequency for all instrumentation must be annual. Calibration records should be maintained in accordance with ANSI N323-1978, Section 4.5.

The instrumentation shall be labeled on their exterior with the following information:[70]

3.5.2.1 Date of the most recent calibration and calibrator used
3.5.2.2 Initials or name of person who performed last calibration
3.5.2.3 Energy correction factors to be used, where required
3.5.2.4 Graph or table of calibration factors, where necessary, for each type of radiation for which the instrument may be used; this should relate the scale reading to the units required if units are not provided on the scale

3.5.2.5 Instrument responsiveness to an identified check source. Source must be identified and expected readings(s) indicated

3.5.2.6 Special conditions (unusual) or limitations on the use of the instrument

3.5.2.7 Date that primary calibration is again required

3.5.2.8 Special condition identification label (if applicable); ANSI N323-1978, Subsection 4.3.1.

Operability checks must be performed every 90 days with the instruments allowed to operate at least one hour during each check. The 4 year calibration frequency provided by FEMA-supported State Maintenance and Calibration Shops for civil defense type instrumentation is not adequate when the civil defense instrumentation is used as REP emergency response equipment. Air sampling pumps must be calibrated annually or after each maintenance or repair. Air sampling pumps must be calibrated in accordance with ANSI N320-1979, Section 9.2,[71] NRC Regulatory Guide 8.25,[72] and American Conference of Governmental Industrial Hygienists manual "Air Sampling Instruments for Evaluation of Atmospheric Contaminants."[73]

In the case of instrumentation used to analyze samples which vary in radioactivity, a range of standards in the appropriate media should be developed which span the range of radioactivity anticipated to be measured. Sampling procedures and analytical techniques should be developed to ensure adequate sensitivity and statistical validity of the data obtained. The participation in the use of round-robin unknown samples for determining accuracy of the total analytical system should be encouraged wherever possible.

6.3 Common Instrumentation Factors

The high-range (100 R/h) and low-range (50 mR/h) exposure rate instrumentation required for the Plume Exposure Rate Verification System and the Emergency Worker Radiation Exposure Monitoring System, should be identical for field monitoring team personnel and emergency workers assigned to traffic control points or similar activities within the plume exposure EPZ. However, the Plume Exposure Rate Verification System requires additional air sampling equipment and measurement (count rate) instrumentation which are not required by the Emergency Worker Radiation Exposure Monitoring System. The Recovery and Reentry Monitoring System and the Ingestion Pathway Monitoring System require more sensitive portable survey instrumentation, such as count rate instruments with 1" x 1" or 2" x 2" (NaI(Tl) detector, or thin window (1.4 - 2.0 mg/cm^2) GM detectors (See Section 4.4). Consequently, the low-level exposure rate instrumentation of the former two systems may not be interchangeable with the latter two systems.

In general, the initial survey team effort (manpower and instrumentation) required for the Exposure Rate Verification and Emergency Worker Radiation Exposure Monitoring Systems within the EPZ area will be nearly constant as a function of time during the first several hours after the accident begins. The first measurements will be directed towards the Plume Exposure Rate Verification measurements, followed by a combination of Plume Exposure Rate Verification measurements and Emergency Worker Radiation Monitoring measurements at designated sites, and for contamination control measurements. Therefore, the survey teams and/or their instrumentation may be shifted among these three types of activities as requirements change.

The instrumentation for the Ingest ion Pathway Monitoring System, and particularly the Recovery and Reentry Monitoring Systems, may require a more sensitive level of detection than is required for the Plume Exposure Rate Verification System. However, this type of measurement will probably not be required until 12 to 24 hours after the start of the release to the off site environment. Guidance on the Ingestion Pathway Monitoring System is the subject of the Phase-2[74] and Phase-3[75] documents. Further guidance for the Recovery and Reentry Monitoring Systems will be the. subject of a future report by the Subcommittee.

6.4 Contamination Control

The emergency planner is required by NUREG-0654, Planning Standard and Evaluation Criteria J.12,[76] to provide the capability for contamination monitoring of all residents and transients, within the plume exposure pathway EPZ, that arrive at relocation centers. This monitoring requirement extends not only to the general public which may be evacuating the area during a large-scale accident with off site consequences, but also to the emergency monitoring team and other emergency workers and their equipment who have been working within the evacuated area. Measurable contamination may be suspected on any person or piece of equipment which has been exposed to levels of radiation greater than 100 mR/h, or to radioiodine concentrations of approximately 20 pCi/cm^3 or greater, or to airborne particulate radioactivity for more than one hour.

6.4.1 Emergency Worker Contamination Control

Screening for the presence of beta and gamma contamination on all emergency monitoring personnel and equipment leaving evacuated/restricted areas is required after returning from their mission(s). As interim guidance, the State or local emergency planner may refer to the Los Alamos Scientific laboratory document, LA-4558-MS,[77] for surface contamination limits. A rule of thumb that may be used as a personnel contamination limit is an open window reading of approximately 60 cpm for a CDV-700 (0.1 mR/h) above the pre-accident background scale reading for low background radiation areas (<0.1 mR/h gamma exposure rate).[78] Other standard low-range GM instruments with a movable window shield are also adequate for use with the limit used being the approximate counts per minute that would correspond to the instruments dial reading for 0.1 mR/h above the background exposure rate in a low background radiation area. Thin window pancake type GM detectors with a count rate meter will be adequate to monitor beta-gamma contamination at the limits specified in the Los Alamos document. A rule of thumb for personnel contamination monitoring with the 'pancake type GSA detector is an instrument reading limit of 100 cpm above background in a low background radiation area. The instrument detectors, used for contamination survey measurement, must be protected against contamination by a thin plastic covering material, such as a baggie.

Wherever possible, monitoring teams equipped with the above instrumentation should be stationed along exit routes leading from the evacuated area and outside the plume/restricted area to monitor emergency personnel, vehicles, and equipment leaving the area. Facilities (water, determent, clean clothing, car washes, fire stations, etc.) to perform the necessary decontamination should be located nearby. Decontamination, particularly of emergency personnel leaving the plume/restricted area, should be instituted as soon as possible, with the establishment of areas that separate personnel who are to be checked for contamination from those who have been decontaminated (hot line, etc. for disrobing, going to the shower, leaving the shower, being remonitored, and dressing again if contamination levels are low enough).

Equipment, materials and clothing which cannot be readily decontaminated should be placed in segregated storage until sufficient time, material, and manpower can be made available to complete the decontamination procedure.

6.4.2 General Public Contamination Control

Additional trained emergency monitoring personnel must be available at relocation centers in host areas for monitoring all arriving evacuees. The actual setup and operation of monitoring stations is considered necessary only if an evacuation has occurred and if a release of radioactivity has occurred. Trained personnel for contamination monitoring and an adequate amount of monitoring equipment should be available to monitor, within about a 12 hour period, all residents and transients leaving the plume exposure EPZ and arriving at relocation centers.[79] States should develop a plan to monitor within about 12 hours a minimum of 20% of the EPZ resident population plus transients at the relocation centers.[c] For planning purposes, the approximate number of monitors needed can be determined based on the following time-related factors: 90 seconds (1.5 minutes) for monitoring each evacuee and a 10-minute break for each monitor per hour, thus leaving 50 minutes for monitoring. As an example, if it was determined that 20% of the total EPZ population plus transients is 6,000 persons and 33 evacuees could be monitored per hour (50 minutes divided by 1.5) and if each monitor worked a 6-hour shift, then approximately 200 evacuees (6 hours X 33 persons per hour) could be monitored during each shift by each monitor. In this example, it would take 30 monitors to monitor the 6,000 evacuees in about a 12-hour period, i.e., two shifts of 15 monitors. This figure would be less conservative if a 10-minute break was not included in the calculations or if the monitors worked longer shifts, i.e., 8 to 12 hours instead of 6 hours.

If additional resources are ever needed in excess of the planning base, it is expected that State and local government will develop ad hoc measures, supplemented, if needed, by Federal and private sector resources. In the cases where large numbers of evacuees are potentially possible, the use of "portal monitors" as an initial screening device would be appropriate.

The monitoring equipment and guidance on contamination limits should be the same as that provided for emergency worker contamination control (see Section 6.4.1). Provisions should be made for scheduling and giving routine examinations for internally deposited radioactive contamination to those evacuees who have been found to have high levels of external contamination.

6.5 Survey Team Manpower Considerations

As discussed above, the same survey teams, with use of the proper instrumentation, can obtain the necessary exposure rate measurements for Plume Exposure Rate Verification Monitoring and Emergency Worker Exposure Monitoring at the assigned emergency monitoring locations. These activities will be primarily confined to the EPZ for the plume. Adequate resources for a duration of a minimum of 18 hours may be needed for Plume Exposure Rate Verification Monitoring, and for Emergency Worker Radiation Exposure Monitoring within this EPZ, at which time, Federal personnel, if needed, may be available to replace them. These State or local emergency monitoring teams will also be useful to acquire environmental samples for Ingestion Pathway Monitoring and for the Recovery Reentry Monitoring System. Radioactive contamination of the

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[c] "Guidance on NUREG-0654/FEMA-REP-1, Evaluation Criterion J.12," Richards W. Krimm letter to Natural and Technological Hazards Division Chiefs, December 24, 1985.

ingestion pathway is likely to occur over an area much larger than the EPZ for the plume pathway consequently, additional sample acquisition and monitoring teams for the ingestion pathway EPZ will be required. These monitoring teams should include a member from the State Department of Agriculture or other agencies which are involved with the routine sample collections of milk and non-dairy foodstuffs.

Manpower for the survey teams to perform Plume Exposure Rate Verification Monitoring and Emergency Worker Radiation Exposure Monitoring should come from the surrounding communities, preferably within a radius of approximately 20 miles from the reactor site. Local and/or State government employees, such as firemen, highway engineers or inspectors, health department personnel, teachers, or possibly local civil defense volunteers should be considered as one source for providing the manpower. (All voluntary personnel must have extensive instrumentation and emergency monitoring procedures training and this training must be maintained by routine refresher training sessions.) Staff from the reactor facility or from the utility company who have no radiological emergency assignments are also another possible source for monitoring teams. However, primary monitoring personnel should be individuals from health department radiation control sections who are adequately trained and able to maintain the required preparedness capabilities on a full time basis. Personnel from the State or local police organization should not generally be assigned to a survey team for Plume Exposure Rate Verification measurements, since they will be needed for other functions, such as setting up road blocks, warning the population to take protective actions, escorting emergency vehicles and directing traffic. However, they should be considered as Emergency Workers and be provided with training and radiological equipment to use for their self protection.

States which have primary responsibility for all emergency response monitoring should establish emergency response teams in the locale of reactor sites. This provision should be made, especially if emergency response teams located at State headquarters cannot respond in a timely manner. Local monitoring teams could be made up of personnel from local government agencies and/or from the utility. All personnel should be properly trained in the characteristics of ionizing radiation and its hazards, use of the instrumentation, monitoring plans and procedures, data documentation, sampling techniques, and other relevant procedures. The technical quality of training should be at the highest practical level and should be taught by qualified technical personnel from the nuclear facility staff and involved State governmental agencies. Such training will require an extensive effort, therefore, personnel selected for training should be those who will likely remain in the community for a long period of time. The training should be continuously updated with hands-on practice in the use of the monitoring systems and with refresher training courses.

6.6 Deployment and Operating Procedures for Survey Teams

Deployment of survey teams following notification of a nuclear accident is an integral part of the Exposure Rate Verification System. Deployment will depend upon the measurement pattern prescribed by the EOC to match the projected exposure rate pattern. Extent of deployment will depend upon constraints, such as availability of motor vehicles, accessibility of the areas, lack of roads, availability of equipment and/or personnel, weather conditions, location of stationary monitors that must be visited by survey teams, and projected high exposure to survey team members. Therefore, it is necessary to establish plans for survey team deployment which will maximize their effectiveness in obtaining survey data. The State or local emergency response plan should provide for use of survey teams from the utility for offsite monitoring during the very early stages of a nuclear accident. The utility supplied offsite monitoring teams can provide necessary measurements until the State or local monitoring teams arrive at the site and are fully briefed on the status of the accident.

No set guidance can be provided to develop an effective survey team deployment plan. Furthermore, it should be kept in mind that subsequent deployment to assess the long-term consequences is a matter of separate concern and will involve considerations not included in the scope of this report.

Emergency plans should be designed to respond to accidents as discussed in detail in NUREG-03962 which recommends adequate flexibility to allow response to the most serious accidents. Thus, the flexibility principle advocated by NUREG-0396[80] should be useful for the development of a survey team deployment plan.

Deployment plans for obtaining information for the Plume Exposure Rate Verification System should contain the flexibility to encounter unexpectedly high radiation levels with the objective of minimizing the radiation exposure to survey personnel. When high radiation conditions exist, protective actions for the general public can be taken without extensive measurement. For example, dose projections based on plant status should be the basis for a protective action, such as evacuation, rather than waiting on field monitoring measurements before making the initial protective action decision.

It should be emphasized that a large number of field monitoring measurements are not required within areas in which an evacuation has been completed. The field monitoring efforts should be concentrated at the edges of the evacuated areas, because a primary responsibility of field monitoring is to determine that the evacuated area is large enough. However, since centerline measurements are required in order to make downwind dose projections, some centerline measurements may be required in an evacuated area.

In addition there are a number of site specific considerations which may need to be evaluated in the development of a deployment plan. Some of these are: (1) the terrain in the area potentially affected, (2) access to the affected area, (3) population concentration, and (4) the remoteness of the site. Some of these considerations can be reflected directly in the plan. For example, if the plume is passing over a remote area with no inhabitants, then there would be less need to assess the plume dose for protective action purposes. However, some deployment is necessary to assure that changes in local meteorology have not caused a change in plume direction toward inhabited locations.

There are a number of points to consider in making decisions as to the number and size of survey teams required for Plume Exposure Rate Verification Monitoring and Emergency Worker Exposure Rate Monitoring. A typical plan to perform the monitoring might call for 5 to 10 teams (a combination of utility teams, State teams, and local teams) of two members each. Actual deployment should be along the direction of plume travel with teams directed to take measurements at points determined by the field team coordinator at the EOC (see Section 4.5 for guidance on selection of survey points). Field monitoring teams should be given tasks to perform rather than just specific locations to report from. For example, a team should be assigned the task of defining the center line of the plume and the plume boundaries at a given distance, e.g., 2 miles, from the site. Reverification may be required whenever meteorological conditions, release rates, or release composition changes significantly. Two-member teams are recommended to assure that measurements are taken and reported in the most timely and efficient manner possible. A 100 percent replacement of survey team personnel should be available as backup in case the release lasts longer than 12 hours. A release duration of at least 18 hours must be considered for planning the required monitoring team personnel resources.

Factors that might impact on the necessary number and size of survey teams are:

A. The geography of the area. The geography and size of the area to be monitored is the most important factor in determining the number of teams needed to adequately perform this function. For example, if a nuclear plant is located at a coastal site where more than half of the area covered by the EPZ is uninhabited open water or swamp land, the number of teams needed to perform offsite monitoring should be significantly smaller than for a site surrounded by populated areas. Other topographical features to be considered include rivers or mountain ranges in the EPZ with a limited number of bridges or crossings requiring long driving distances to get across these barriers. Also meteorological characteristics such as high wind variability and weather conditions that impede vehicle movement should be considered. The demographics of the area must also be considered in determining the need for greater or less accuracy by requiring more or fewer measurements.
B. Phased Deployment. The plan should provide for phased survey team deployment in order to obtain measurements at approximately the same time or at desired time sequences.
C. The number of preselected monitoring points for which measurements are to be made and the type of measurements to be made at each preselected point.
D. The type and number of instruments available. The availability of instruments will determine the number of teams which can be gainfully deployed.[d] Inadequate instrumentation could severely curtail the effectiveness of the Plume Exposure Rate Verification Monitoring System.
E. The availability of trained survey team members.
F. The time required for survey team members to arrive at the assigned location and to prepare for and conduct monitoring activities.
G. The length of time that the release is expected to continue (resurvey will be necessary for releases lasting over several hours).

Figure 4 illustrates an example of how monitoring teams might be deployed to measure and verify an offsite release. The figure shows three monitoring assembly points (MAPs) from which the teams have been deployed. All the survey routes are along roads, streets and highways in the geographical area. The deployment is based on the assumption that the plume is within a three-sector wide area to the south of the site and covers a downwind distance of about nine miles from the site boundary. Two gamma isodose rate lines resulting from the contribution of radioiodines and noble gases in the airborne plume are portrayed within the area. The x's along the survey routes are to illustrate the preselected monitoring points where each team is to take measurements. It should be noted that the two teams (1-2 and 2-2) which were assigned routes near the reactor site on the downwind side have turned back because the radiation readings (greater than 1-5 R/h) encountered exceeded their operating limits. (The high exposure rate in

[d] The need for the additional survey data versus the radiation exposure likely to be received by the surveyors should be carefully evaluated.

this case is due to the high-level inhalation exposure from radioiodine, approximately 20 pCi/cm^3, which gives a projected thyroid dose of more than 5 rem after a one hour exposure. Also, it should be noted that the preselected monitoring points are closer together near the site and around the small town located to the south of the site where more definition of the exposure rate variations is desired.

See attachment for image – Figure 4

Figure 4. Example of Deployment of Monitoring Teams

The types and quantities of support equipment needed for deployment of the survey team should be evaluated based on the need for: (1) personnel protective equipment, (2) vehicles, (3) communication equipment, and (4) an adequate supply of high-quality area maps showing preselected reference locations. Protective equipment should also be evaluated for adequacy to provide protection against radiation inhalation and particulate contamination. Guidance on respiratory protection equipment can be found in the EPA Manual1 and NUREG-0041, "Manual of Respiratory Protection Against Airborne Radioactive Materials."[81] Equipment of this type should be made available at the MAPs. Additional equipment that might be of value in emergency operations are listed in the following publications:

- M. Hunt, Ed., Emergency Monitoring Procedures; University of Nevada, Las Vegas, Nevada (August 3, 1970).
- Radiological Emergency Operations, USAEC TID-24919, Students Manual (July 1968).
- Nuclear Accident Contamination Control, Department of Army Field Manual FM3-15 (November 1975).

Considerations should be given to either supplying all deployed teams with radio communications or identifying the location of telephone facilities convenient to preselected monitoring points. Public service facilities, e.g., fire trucks and highway maintenance trucks may be an excellent source of radio equipped vehicles. Police vehicles are not recommended for consideration as they will likely have other assignments. Scheduling of team reports may be necessary to prevent an overburden on the radio and telephone facilities at the EOC.

6.7 Federal Resources Available

In addition to readily available State and local resources, the deployment plan should include the use of Federal resources which are discussed in Appendix A of this report, i.e., AMS, ARAC, RAP, and FRMAP, as these resources will be of valuable assistance in providing input for determining the need for protective actions, once they arrived on the scene. One important resource is the local or regional facilities of the National Oceanic and Atmospheric Administration (NOAA) which can provide input on the meteorological situation in terms of wind direction, temperature and wind speed at locations other than on the site. This input may improve the meteorological model for making offsite dose projections. Also NOAA can provide forecasts of the changes in meteorological conditions which can be used to determine how long the present dose projection will be valid and when changes in the meteorology will make it necessary to make new projections or take different protective actions.

In order for all of these resources to be of maximum value, they should be incorporated into the overall plan for the deployment of monitoring teams and making dose projections. The State should plan to obtain Federal assistance by contacting FEMA and the DOE Regional Coordinating Office. As part of the deployment plan, consideration should be given to the Federal monitoring team response time following initial notification, the maximum expected available Federal manpower, and the assistance which can be provided by RAP or FRMAP in determining their effectiveness for offsite monitoring support. This is more cost effective than having each State duplicate the extensive response capability of the Federal government.

6.8 Logistics Planning

A logistics plan is needed to support the monitoring plan to ensure that the required resources reach the appropriate location at the proper time. A good logistics plan can alleviate many of the constraints of the deployment of survey teams such as insufficient equipment and/or survey teams and some of the problems associated with lack of roads or inclement weather.

For example, the logistics plan might call for MAPs at about 10 mile radius of a sector with two survey teams per MAP. The MAPs should be strategically located to provide easy access by monitoring team members, e.g., if team members have to travel long distances, it may be necessary to have the MAP located near a local airport. These MAPs may be used as communication and resupply posts. Fire or police stations would be desirable for MAPs because emergency communications with the EOC would be available. Also, vehicle fuel and emergency vehicles may be available. Trained volunteers survey team personnel may normally report to these stations, and the survey team equipment should be stored at the MAP.

Each survey team should be equipped with both high (100 R/h) and low (50 mR/h) range field gamma exposure rate instruments. Based on the radioiodine measurement system described in Section 4, one portable airborne radioiodine sampler is also required for each team. In addition, spare instrumentation should be available in case of malfunction of some of the instrumentation. The usual criteria for instrumentation with proven reliability is to provide about 20 percent spare instrumentation. Each survey team member should be equipped with personal dosimeters as described in Section 5.

For local offsite monitoring teams as most facilities, the needed gamma instrumentation to implement the Plume Exposure Rate Verification System can be made available through the Civil Defense organization in their State, although it may have to be redistributed for an effective logistics plan. Also, Civil Defense instrumentation would have to be calibrated at the frequency set forth in the State emergency response plan.

If this is implemented, the cost of additional equipment to supplement available instrumentation is expected to be small. The number of instruments needed, and hence the cost of supplemental instrumentation, depends upon the monitoring plan. Once the minimum requirements of the monitoring plan have been met, which are that the plan be adequate to provide the needed measurements for any set release and meteorological variations, then the effectiveness of the plan increases slowly wit the number of additional instruments in use. On the other hand, the effectiveness of the plan decreases rapidly with the decrease in the number of instruments available, resulting in inability to meet the minimum requirements of the plan. If only a few measurements are made about the same time, they will not give adequate spatial coverage, of if these few measurements are made at different times, they will not be as useful for developing exposure rate contours. Also, the effectiveness of the monitoring plan to respond to changes in wind direction will decrease with decrease in the number of instruments available below the minimum requirements.

In addition to the instrumentation required for teams to verify the projected release pattern, it is recommended that all personnel involved in setting up road blocks or other access control points restricting public access into the area where the radiological hazard is believed to exist be equipped with gamma radiation rate measuring instrumentation. The reason for this recommendation is to ensure that these control points are outside the hazard area. These personnel should be instructed to make radiation measurements at the time the control point is established and periodically throughout the incident (at least once per hour). These measurements also will give the EOC personnel plotting the radiological data some additional monitoring information. The personnel used for setting up theses access control points should be given training in the proper use and operation of the radiation rate measuring instruments.

The minimum instrumentation provided to the personnel at each access control point should be one low-range gamma measuring instrument capable of measuring at least 50 mR/h and meeting the specification requirements of Appendix E of this document. This is additional to the dosimetry recommended for all emergency personnel as described in Section 5.

6.9 Use and Availability of Laboratory Based on Gamma Ray Spectrometers and Associated Instrumentation

Although the use and need of NaI (Tl) or GeLi gamma ray spectrometers is completely covered in the Phase-2[82] and Phase -3[83] documents developed by the FRPCC Subcommittee, it is briefly included in this document because the need for such instrumentation at the accident scene is essential fro evaluating air samples to determine the exact composition of the plume and its effects on the offsite environment. Because of the possibly large number of radionuclides in the plume and the broad spectrum of gamma energies that may be present, the use of the GeLi detector and a multichannel analyzer with a spectrum stripping capability will likely be required to determine the amount and type of radioactivity.

The need for gamma ray energy measurement instrumentation is not immediate, because the early decisions for protective action for the population will be based on the initial projections from the facility augmented by field evaluation of the plume for radioiodine by local monitoring teams. However, laboratory instrumentation of this type should be available for offsite monitoring within 10 hours after the start of the accident. Gamma ray energy measurement instrumentation should be available at the State Health Laboratory, however, if not, it can be provided by the DOE RAP or FRMAP teams. It should be pointed out that, although many nuclear power facilities are equipped with this type of instrumentation, its availability is questionable for the following reasons:

a. The onsite monitoring requirements may overload the capacity of the instrumentation to make analyses.
b. The base line background of the instrumentation may be lost due to the high radiation levels in the facility

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APPENDIX A – FEDERAL ASSISTANCE TO STATES IN IMPLEMENTATION AND SUPPORT OF THE MONITORING SYSTEM

This appendix describes Federal agencies available to assist States in implementation of their monitoring system. A summary of the functions and capabilities of each Federal Agency Program is stated and recommendations are made as to how the agency program can best assist the States.

1. Federal Radiological Emergency Response Plan (FRERP)

The current plan (see Section 2 below) for significant Federal response to radiological emergencies is directed primarily toward responding to accidents at commercial nuclear power plants. A new plan, the Federal Radiological Emergency Response Plan (FRERP)[1], has been implemented which consolidates the Federal response to a wide range of potential radiological emergencies. The scope of the FRERP includes all types of civil radiological emergencies that might require a significant Federal response in support of State and local governments.

The FRERP is the single Federal plan for coordinating the Federal response to any civil peacetime radiological emergency requiring a significant Federal response. The FRERP is intended to facilitate and clarify the Federal role and mechanisms for providing support to State and local governments in a major radiological emergency, if Federal support is required. The twelve Federal agencies which are signatory to the FRERP are: Department of Commerce (DOC), Department of Defense (DOD), Department of Energy (DOE), Department of Health and Human Services (HHS), Department of Housing and Urban Development (HUD), Department of the Interior (DOI), Department of Transportation (DOT), Environmental Protection Agency (EPA), Federal Emergency Management Agency (FEMA), National Communications System (NCS), Nuclear Regulatory Commission (NRC), and U. S. Department of Agriculture (USDA).

2. Federal Radiological Monitoring and Assessment Plan (FRMAP)

The Federal Radiological Monitoring and Assessment Plan (FRMAP) was developed by the U. S. Department of Energy (DOE) under 44 CFR Part 351 issued by the Federal Emergency Management Agency (FEMA) on March 11, 1982. FRMAP is a part of the FRERP and replaces the Interagency Radiological Assistance Plan (IRAP) originally published in 1965 to provide Federal technical assistance and response to radiological emergency incidents. Conceptually, FRMAP was derived from the IRAP; the most significant changes are in the designation of participating Federal agencies, and in some cases, their expanded/new responsibilities, e.g., FEMA. The purposes of FRMAP are as follows:

- To make needed radiological assistance available to the general public, State, and local governments, and Federal agencies

- To provide a framework through which Federal agencies will coordinate their emergency monitoring and assessment activities in support of State and local government radiological monitoring and assessment activities, and

- To assist State and local governments in preparing for radiological emergencies by describing Federal assistance responsibilities and capabilities

The provisions of FRMAP apply to the Federal agencies given radiological emergency assignments by the Federal Emergency Management Agency in 44 CFR Part 351 (47 FR 10758) dated March 11, 1982, Radiological Emergency Planning and Preparedness Federal Regulations and were developed by the Department of Energy. The agencies participating in the FRMAP include the Nuclear Regulatory Commission (NRC), the Environmental Protection Agency (EPA), the Department of Health and Human Services (HHS), the Department of Energy (DOE), the Department of Agriculture (USDA), the Department of Defense (DOD), and the Department of Commerce (DOC). The FRMAP recognizes that the above agencies may have other radiological planning and emergency responsibilities as part of their statutory authority. The provisions of the FRMAP do not limit those responsibilities, but they provide for a coordinated Federal response when emergency radiological assistance is requested.

The underlying assumptions of FRMAP are as follows:

1. The participating Federal agencies will develop plans and supporting procedures at the national and regional level to implement FRMAP. These plans will be consistent with any planning requirements placed on the State and local governments and specific facilities for such radiological incidents as identified by FEMA and presented in NUREG 0654.

2. The participating Federal agencies will maintain facilities, equipment, and personnel to carry out their statutory responsibilities. Radiological monitoring and assessment capabilities developed to carry out those responsibilities will be made available to other Federal agencies, to State and local authorities, and to the general public, in an emergency if needed or required.

3. The Federal agencies will make resources available upon request, including national emergencies, only to the extent that the agencies can also continue to carry out their essential missions and emergency functions.

4. When participating Federal agencies make their resources available in emergencies, the DOE will coordinate all Federal offsite radiological monitoring and assessment operations and integrate the data derived from these activities during the emergency phase. The EPA will assume this role in the intermediate and long-term phases. An agency making its resources available, although under the general direction of DOE, does not place itself under the authority of DOE.

5. The DOE (and subsequently EPA) will maintain a common and consistent set of all offsite radiological monitoring data and provide it, with interpretation, to the cognizant Federal agency and to the states and other groups as required.

6. Federal radiological response will be in support of and integrated with that of the State and local governments. Their sources of DOE and the participating agencies should be used only when State and local resources are not adequate. However, if a release of significant radioactivity is anticipated, consideration should be given

to the early request for assistance. This is because the Federal government has most of the resources needed to support the State in dealing with a major accident.

7. The Federal monitoring effort will be initiated through a request from a State or local government, another Federal agency, private entity, or in rare cases, when DOE, after notification of an incident, believes there is a possibility of hazard.

8. Federal agencies, to the maximum extent possible, will assist other Federal agencies, and State and local governments with planning and training activities designed to improve local response capabilities, and will cooperate in drills, tests, and exercises.

9. Funding for each agency's participation in support of the FRMAP is the responsibility of that agency.

The Federal Response Subcommittee of the FRPCC, consisting of representatives for each of the participating agencies, serves as the continuing coordinating body for the FRERP, and thus the FRMAP. This subcommittee interprets, maintains, and updates FRERP. The subcommittee, which is chaired by the representative of FEMA, also provides a means for coordination of response capabilities, training activities, exercises, and research and development pertinent to the FRERP and FRMAP. Regularly scheduled meetings will be held and each agency reports to the subcommittee periodically on its radiological response capabilities, training programs, and research and development activities designed to improve their response resources.

The FRMAP recognizes that the appropriate response to a request for Federal radiological assistance may take many forms, ranging from advice given by telephone to a large, Federal monitoring and assessment operation at the site of a serious accident. Most of the operational management guidelines that follow are designed for the latter situations. The FRMAP, however, also provides the authority for cooperation, coordination, and interagency assistance when a large Federal response is unnecessary, and a limited response, possibly by DOE alone, is sufficient.

Each participating agency maintains national and regional emergency response capability, as necessary, for it to carry out its statutory responsibilities. Offices and personnel available for conducting the agency's normal operational duties may be utilized to provide facilities, equipment, supporting staff, and technical operations personnel for implementing FRMAP.

Each participating agency is responsible for developing plans and supporting procedures to implement FRMAP. Where appropriate, the plans are specific for each region and responsive to each type of radiological incident. Other FRMAP agencies coordinate among themselves at field level. The plans established are consistent with plans of State and local governments, e.g., emergency plans in the case of nuclear power plant incidents, and are consistent with Criteria for Preparation and Evaluation of Radiological Emergency Response Plans, and Preparedness in Support of Nuclear Power Plants NUREG-0654, FEMA-REP. 1, Rev. 1, Nov. 1980. Where appropriate, the plans and supporting procedures include information on:

- resources available
- inter- and intra-agency notification procedures
- organization, jurisdiction, and responsibilities of the response resources

- estimated activation times for different types of response
- internal emergency operation guidelines
- mechanisms for handling the logistics for personnel and equipment at the scene of the incident
- interagency training and exercises to be coordinated through FRPCC
- other material considered appropriate by the agency

The implementation plans of the participating agencies are reviewed by DOE and integrated into the DOE FRMAP implementation plan. Regional plans of participating agencies are forwarded to the DOE Regional Coordinating Office(s) serving the region.

Requests for radiological assistance may come from other Federal agencies, State or local governments, licensees for radiological materials, or the general public. Appropriate requests are also referred to DOE by the National Response Center, operated by the U. S. Coast Guard primarily to receive reports of accidental discharges of petroleum products, and the Chemical Transportation Emergency Center (CHEMTREC), an emergency assistance center sponsored by the Chemical Manufacturers Association.

A general scheme for the management of the total Federal response to a radiological emergency is shown in Figure A-l. The Federal role is to assist the States during the emergency. In order to do this, the Federal response is divided into technical and non-technical support. FEMA coordinates non-technical support while the cognizant Federal agency (the agency controlling or having regulatory authority over the facility in which the incident occurred or the radioactive material involved in the incident) coordinates the technical support. The technical support is separated into onsite and offsite support, with DOE coordinating the Federal offsite radiological monitoring and assessment activities during the emergency phase. During the intermediate and long-term phases, the EPA assumes this role. The FRMAP primarily addresses this offsite portion of the larger Federal response. Following receipt of FRMAP information, recommendations for protective actions are made by the cognizant Federal agency jointly with FEMA to the State and local governments. The participating agencies may also provide resources directly to the cognizant agency when needed. The State Department is responsible for coordinating the Federal government's response to major non-military emergencies with international implications.

See attachment for image – Figure A-1

Figure A-1. Federal Response Management for a Radiological Emergency

Emergency actions are taken by the participating Federal agencies to save lives, minimize immediate hazards, and to gather information about the accident that might be lost by delay. Such action does not preempt a later implementation of the FRMAP.

DOE's coordination and leadership responsibilities under FRMAP are applied at both the regional and national level. DOE maintains national and regional coordinating offices as points of access to Federal radiological emergency assistance and response. Requests for Federal radiological assistance are made through the Regional Coordinating Office. An exception to this is a request from the DOD, which will be made through the DOD-DOE Joint Nuclear Accident Coordinating Center (JNACC) in Albuquerque, New Mexico. The DOE regional office responds by dispatching & Radiological Assistance Program (RAP) team, by requesting assistance from a regional office of another participating agency, or by referring the request to an appropriate State agency that can provide prompt assistance. Close contact is maintained between the DOE regional and national offices.

DOE maintains a state-of-the-art capability to respond to any radiological incident throughout the nation. This response can be directed from either the regional or the headquarters level. As noted, DOE transfers responsibility for Federal coordination of intermediate and long-term monitoring to EPA at an appropriate time.

3. Major DOE Resources

Emergency response activities are highlighted by unique resources to monitor and assess any accidental release of radioactivity from a nuclear facility. Aircraft of the Aerial Measuring System (AMS) are maintained to be ready to apply state-of-the-art remote sensing equipment to map large areas that may have been affected by an accidental release. A computer-based system, the Atmospheric Release Advisory Capability (ARAC) uses actual weather and terrain data to predict on a regional scale the transport, diffusion, and deposition of any radioactivity released to the environment. Complementing these systems is an experienced cadre of scientists, engineers and technicians available to assist local authorities and to coordinate DOE and other Federal responses to an accident. A more detailed description of these resources follows.

3.1 Aerial Measuring System (AMS)

The Aerial Measuring System (AMS) is a state-of-the-art aerial radiation surveillance program operated under the Department of Energy.[2] AMS consists of rotary and fixed wing aircraft equipped with gamma ray and neutron detectors. In the east, the AMS is based at Andrews Air Force Base, Maryland, and in the west at Las Vegas, Nevada.

The AMS program, initiated in 1958 by the AEC, is directed toward obtaining surveys of gamma data (gross and spectral) that can be used to assess changes in environmental levels of radiation from nuclear tests, operation of nuclear facilities, and radiation incidents. The AMS capability has also been used to follow the movement of radioactive clouds from above ground nuclear weapon tests and from venting of underground tests. The system is potentially very useful in defining the boundaries of the contaminated area, especially if a large contaminated area is expected. The AMS detector system consists of an array of twenty 5"x2" NaI(Tl) scintillation crystals which are equally distributed within two cargo pods.[3] This system is effective for detecting and identifying gamma emitting radionuclides which have energies greater than 50 keV. The helicopter mounted detector system has a sensitivity range of 0.1 to 1.0 $\mu Ci/m^2$ for gamma energies greater than 50 keV. The fixed-wing aircraft detector system has a sensitivity ranging from 1.0 to 10 $\mu Ci/m^2$ for similar gamma energies.[4] However, at gamma energies between 50 and 100 keV, the detection limit is highly dependent on the geometry of the source and its distribution in the soil. The difference in sensitivity between these two aerial systems is due to the helicopter's ability to be flown at lower altitudes and at lower air speeds than the fixed winged aircraft.

The normal data output from AMS is in units of microroentgens per hour (µR/h) extrapolated to one meter above ground level.[5] The data from the aerial radiological survey is recorded on magnetic tapes for further data reduction using a ground based computer system.

The AMS program is directed toward a schedule of surveys made to acquire background data prior to construction of a nuclear facility and also to study the changes in levels after an incident. Preoperational surveys are made at all nuclear power reactor sites, and these surveys are periodically updated at 3 to 5 year intervals for most facilities. A periodic update survey to measure environmental buildup of long-lived radionuclides is made for all nuclear facilities in order to determine the baseline for post nuclear incident restoration.

AMS has the capability to track the plume of a radionuclide release, taking measurements and determining its direction and dispersion.[6] However, its greatest value in terms of radioiodine deposition is for aerial surveys of deposited materials after the plume or radioactive cloud has dissipated.

In the event of a nuclear accident at a facility, the current AMS response would be to send an AMS aircraft to the site and to airlift a mobile data van, which is used to analyze AMS data, to a nearby airport. The maximum AMS response time from notification to the start of aerial measurements at any nuclear facility is estimated to be about 4 to 6 hours for the deployment of an east coast or a west coast AMS capability. A maximum lead time of 12 hours is desired for ground measurements, such as for radioiodine and particulates. Since it is not necessary to begin foodstuff monitoring for 36 to 48 hours following the start of the accident, AMS could survey the area surrounding the site prior to monitoring for radioiodine on foodstuffs. This would allow authorities deploying monitoring teams to concentrate the initial monitoring effort in areas where greatest radioiodine deposition has occurred. The detection limit for AMS is approximately 90% of the preventive response level for I-131 and approximately 5% for the preventive response level for cesium nuclides deposited on leafy vegetables (this is not true for produce since the derived preventive response levels are much lower because of a higher ingestion rate for produce). Therefore, AMS should be used to rapidly determine the areas where the highest deposition of radionuclides has occurred. This information would be especially critical if a shortage of personnel for monitoring teams existed.

Generally, aerial radiological surveys are capable of: 1) detecting areas of enhanced radiation; 2) determining the average surface area exposure rate; and 3) identifying the specific radionuclide(s) responsible for any observable anomaly.[7] However, this system has the following limitations: 1) it may be grounded by inclement weather conditions either at the home air base or at the accident site; 2) it can only detect gamma emitting radionuclides; 3) it is unable to distinguish between contamination on the crops and contamination on the ground; 4) it is of little or no value for detecting waterborne releases; and 5) it may underestimate the magnitude of localized sources, since aerial detection systems tend to average gamma exposure rates over a large area.

The current AMS operational plan is to make the data from the aerial surveys available to the DOE official directing the FRMAP response. The concerned State authorities are also provided access to the AMS data evaluation. Therefore, the AMS should be located near and in constant communication with the State or local BOC where the event is in progress.

The AMS will also be used to supplement the Atmospheric Release Advisory Capability (ARAC) by updating the model from actual measurements taken during the release. This information is valuable in planning initial ingestion pathway monitoring by predicting where areas of greatest radioiodine concentration will occur.

3.2 Atmospheric Release Advisory Capability (ARAC)

The Atmospheric Release Advisory Capability (ARAC) is an atmospheric modeling system based at Lawrence Livermore National Laboratory (LLNL). It is linked by real time to the National Weather Service and the USAF Global Weather Control. ARAC input can be a unit source term or a more refined one, plus local meteorological and topographical conditions. ARAC can predict the atmospheric diffusion of a plume of released material as influenced by the previous mentioned conditions using a suite of computer codes and models ranging from simple Gaussian to complex three dimensional particle-in-cell models. The radionuclide concentration patterns are then projected into both external and internal dose patterns for use in providing assessments to Federal officials, State and local agencies, if requested by them, and AMS monitoring and sampling aircraft.

Currently, real time ARAC output can be made available to any user (through authorization by DOE headquarters) by facsimile transmission from LLNL, as was done at Three Mile Island both during the 1979 accident and the 1980 Kr-85 purging operation. Local meteorological towers can usually be linked directly to the LLNL computer facility, which does the necessary calculations including local topography (LLNL has on file the topography of the entire continental United States),[8] and generates printouts at the laboratory. ARAC personnel can then transmit these printouts via telephone telecopier to the user

The information provided by ARAC can be valuable for planning the deployment of personnel and available resources to the most effective locations. Full ARAC service requires extensive "customization" of information pertaining to a specific site, as well as developing the topographic files for use in ARAC calculations. Beyond the five sites "customized" for selected purposes, there are no plans to "customize" other commercial nuclear power plant sites for ARAC. In actual emergencies partial ARAC service at other than the five "customized" sites can be provided in about 1-4 hours.

3.3 Radiological Assistance Program (RAP)

The DOE Radiological Assistance Program (RAP) has been in operation for over 25 years. Its function is to respond, on an emergency basis, with appropriate scientific and medical advice and technical assistance to incidents involving loss of control over radioactive materials. The DOE provides appropriate radiological advice and assistance as needed from its operations offices and national laboratories to minimize injury and protect public health and safety. It is initiated upon request from any agency, organization, or individual who has knowledge of a possible hazardous incident involving radioactive material.

For the purposes of responding to a radiological accident, DOE has divided the country into eight radiological assistance regions, as shown in Figure A-2. These regions are resource-oriented, centered about major DOE national laboratories and operations offices where the DOE resources are continuously available. DOE has named one of its field office staff in each of the eight regions as the Regional Radiological Assistance Coordinator. These officers are equipped to receive and respond to requests for radiological emergency assistance on a 24-hour basis. The response may range from providing expert advice to mobilizing and dispatching a specially equipped team of radiation emergency specialists.

See attachment for image – Figure A-2

Figure A-2. DOE Regional Coordinating Offices for Radiological Assistance

Food and Drug Administration (FDA) Analytical Capabilities

The FDA Total Diet Study is conducted by FDA's Center for Food Safety and Applied Nutrition and consists of collecting a representative sample of foods in a typical diet at varying locations throughout the country. Samples are composited into food categories, including dairy products, at FDA's Kansas City District Laboratory. Subsequently, composites are sent to FDA's Winchester Engineering and Analytical Laboratory (WEAC) for determination of commonly appearing radionuclides such as tritium and Sr-90, as well as gamma emitters like Cs-137 and K-40, which are readily detected by simple gamma scan.

Under emergency conditions, the WEAC facilities can be used to analyze milk samples submitted by FDA regional field staff. Within FDA, technical staff of the Center for Devices and Radiological Health and the Center for Food Safety and Applied Nutrition can oversee data interpretation; Quality assurance procedures are managed by WEAC staff in cooperation with EPA.

4. Environmental Protection Agency (EPA) Milk Monitoring Net

The EPA milk monitoring net is a part of the EPA's Environmental Radiation Ambient Monitoring System (ERAMS). ERAMS maintains a continuing surveillance of radioactivity in the United States to identify the accumulation of long-lived radionuclides in the environment. However, ERAMS is also designed to provide short term evaluation of large scale environmental nuclear releases, such as from fallout or a nuclear power plant accident. These are composite samples based on the volume of milk sold by various processors in a sampling station area. Gamma analyses are performances on milk samples as soon as they are received. Results of the analysis of iodine-131 content are available within hours.[9]

During radiological incidents ERAMS capability may be utilized to collect and analyze additional milk samples marketed in areas receiving fluid milk from the affected milk shed. The results are provided to the Emergency Operations Center for State and local officials and provides them with a backup system to determine the effectiveness of preventive actions taken to reduce projected dose.

5. NRC, DOE, and EPA Mobile Computer Based GeLi Detection Systems

Although it is not feasible to have sufficient computer based gamma counting systems available near each reactor site to respond to emergency situations, there are mobile systems which can be brought to an accident site. The NRC has five mobile systems, one in each of its regions. A sixth system is operated by the EPA in Montgomery, AL. A seventh mobile system operates out of the Idaho National Engineering Laboratory. All seven of these mobile systems have ongoing functions in research and surveillance programs.

Other National Laboratories may also have similar mobile systems which could be used to help determine radionuclide levels in contaminated samples. The systems are manned by trained personnel and are ready for emergency use if requested by State or local officials. These systems should be considered in addition to the normal emergency response equipment maintained by DOE laboratories.

APPENDIX A – REFERENCES

[1] Federal Register, "Federal Radiological Emergency Response Plan (FRERP); Currerence by All Twelve Federal Agencies and Publication as an Operational Plan," Vol. 50, No. 217; pp 46542-46570.

[2] Edgerton, Germeshausen, and Grier, Inc., Las Vegas Area Operations, An Overview of the Aerial Radiological Measuring System (ARMS) Program EGG-1182-1637 (March 1975).

[3] D.P. Colton, An Aerial Radiological Survey of the Three Mile Island Nuclear Station, Report No. EGG-10282-1021, Las Vegas, NV: EGG/EM (August 1983).
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[4] L.J. Deal and J.F. Doyle, III, An Overview of the Aerial Radiological Measuring System (ARMS) Program, Report No. EGG-1183-1637, Las Vegas, NV: EGG/EM (March 1975).

[5] Ibid., D.P. Colton.

[6] Edgerton, Germeshausen and Grier, Inc., Santa Barbara Division, Aerial Radiological Measuring Systems (ARMS) Equipment and Procedures through FY-66 EGG-1183-2083, S-323-R (March 1966).

[7] Ibid., D.P. Colton.

[8] M.H. Dickerson, et. Al., Lawrence Livermore National Laboratory, ARAC Status Report: 1985, UCRL-53641 (May 1985).

[9] U.S. Environmental Protection Agency, EPA Assessment of Fallout in the United States from Atmospheric Nuclear Testing on September 26 and November 17, 1976, by the People's Republic of China EPA-52015-77-002, (August 1977).

APPENDIX B – INCIDENT NOTIFICATION AND PLUME DOSE PROJECTION SYSTEMS

1. Onsite Nuclear Incident Detection System

The Onsite Nuclear Incident Detection System sensors for an Onsite Dose Projection System operated by the facility should include the "normal" and "emergency" (high range) radiation monitoring instrumentation that is presently required (see 10 CFR 50, Appendix A, Criterion 13,[1] and NRC Regulatory Guide 1.97[2]) to monitor continuously the effluent in all of the most likely potential release paths from the reactor. These should include stack and vent monitors for gaseous and particulate releases as well as liquid effluent monitors located at any point through which contaminated liquids may be discharged. This instrumentation should be supplemented by the plant's Area Radiation Monitoring System for detection of releases from other more unusual routes, high range gross gamma detectors located inside the containment to determine the quantity of radioactive material available in containment for release (source term), and sets of portable monitors to enable monitoring of radioactivity that may be released through other routes. Further requirements could include a ring of gross gamma detectors located at or near the exclusion area boundary (100 to 300 meters from the reactor) that would provide backup to the other systems by detecting the passage of any airborne accidental release without regard to the release route used. Such a system is described in part IV.A of BNWL 1635.[3] Data from onsite meteorological instrumentation specified by Regulatory Guide 1.23[4] would be used for determining the local propagation conditions to forecast the direction and rate of travel of the release.

2. Plume Dose Projection System

Two systems for projecting the dose rate in the environment from the airborne release from a nuclear accident at a fixed facility have been identified. These systems are:

1. An Onsite Dose Projection System operated by the facility

2. An Offsite Dose Projection System, which would be operated by the State or local government to supplement the above system.

2.1 Onsite Dose Projection System

The output of the instrumentation from the Onsite Nuclear Incident Detection System may be used in conjunction with an NRC required system operated by the facility for quickly estimating the projected downwind dose contour patterns. One approach might be to prepare simple map overlays indicating plume diffusion for a variety of typical meteorological conditions at the plant site. Alternatively, a small computer system onsite could be used to provide isodose contour data. A complex and potentially more sophisticated approach to dose calculation might be to use the capabilities of a large centrally located computer. This system would evaluate data from current regional meteorology and from onsite detectors or other release information. This system would then calculate the projected dose and provide estimates of deposition and relative concentration of radioactivity within the plume exposure and ingestion pathway EPZs for the duration of the release.

Regardless of the onsite dose projection system utilized by the facility, it must have modeling and calculational capability which can produce initial transport and diffusion estimates for the plume exposure pathway EPZ within 15 minutes following the classification of an accident.[5] The system model shall use actual 15 minute average meteorological data from the meteorological measurements systems maintained by the licensee. The selected data shall be indicative of the conditions within the plume exposure EPZ. The model shall provide calculations or relative concentrations and transit times within the plume exposure EPZ. Atmospheric diffusion rates shall be based on atmospheric stability as a function of site-specific terrain conditions. Site-specific local climatological effects on the trajectories, such as seasonal, diurnal, and terrain-induced flows shall be included. Source characteristics (release mode, and building complex influence) shall be factored into the model. The output from the model shall include the plume dimensions and position, and the location, magnitude, and arrival time of: (1) the peak relative concentration and (2) the relative concentrations of appropriate locations. The bases and justification for these model (s) and input data shall be documented. The performance and limitations of the model (s) shall also be included in the documentation.[6]

However, there are difficulties with onsite dose projection capabilities because of simplified diffusion calculations, the use of local meteorological input data, and the lack of off site dose verification capability, which limit their usefulness to distances out to approximately 5 kilometers from the site during the first few hours after the start of the release.

2.2 Offsite Dose Projection System

In addition to a computer modeling capability similar to the Onsite Dose Projection System, there are several procedures available to the State EOC for estimating projected plume dose patterns described in the EPA Manual.[7] These methods are based on the following relationship for any specific point in the pattern.

Projected dose = (gamma exposure rate) • (dose conversion factor) • (duration of exposure)

Nomographs are shown in the EPA Manual[8] for determining the dose conversion factors for obtaining projected whole body external gamma and projected thyroid dose from inhalation of I-131. One procedure for using the nomographs requires a determination of the following ratio:

$$\frac{\text{Radioactive iodine concentration}}{\text{Radioactive noble gases concentration}}$$

If this ratio is not known, then the EPA Manual[9] conservatively assumes the ratio to have an initial value corresponding to a postulated release in which 25 percent of the available radioiodines and 100 percent of the noble gases are released to the atmosphere. Methods of estimating the duration of exposure are also given in the EPA Manual.[10]

2.2.1 Dose Projection Methods

Four methods for determining gamma exposure rate patterns are described in the EPA Manual.[11] These methods may be considered as independent alternatives, but they can also be logically considered to be sequential steps for developing an accurate gamma exposure rate pattern as the incident develops in time. These methods are briefly described below.

Method 1 - Estimated gamma exposure rate patterns are provided by the facility based upon onsite measurements. Projected dose patterns are estimated from these exposure rate patterns.

Method 2 - Obtain a few gamma ray exposure rate measurements along the downwind axis of the plume and use an R^{-1} relationship to estimate the gamma exposure rate pattern from which a projected dose pattern is estimated, where R is the downwind distance from the facility.

Method 3 - Select a previously prepared isopleth (overlay) to fit the dispersion pattern for the prevailing meteorological conditions. Obtain a pattern of gamma exposure rate measurements on and about the downwind axis of the plume to compare to the exposure rates associated with the selected isopleth curves. Use this isopleth to estimate exposure rate patterns in unmonitored areas. At this stage, more measurements are available and a more accurate prediction may be made than from the above methods.

Method 4 - Develop a gamma exposure rate pattern based on a large number of gamma exposure rate measurements. This pattern is used to develop projected dose patterns. At this stage, which might be several hours after the start of the release, many measurements could be available to make an accurate projection, but its main value would be for areas at greater distances from the facility because protective actions should have been taken by this time at close distances.

3. Atmospheric Release Advisory Capability

Another modeling system which may be used in conjunction with either the Onsite or Offsite Dose Projection Systems is the Atmospheric Release Advisory Capability (ARAC). The ARAC is an atmospheric modeling system based at Lawrence Livermore National Laboratory.[12] It is linked by real time to the National Weather Service and the USAF Global Weather Control. ARAC input is a unit source term (unless a more refined source term is available) and local meteorological conditions. ARAC can predict the atmospheric diffusion of a plume of released material as influenced by the previous mentioned conditions using a suite of computer codes and models, ranging from simple Gaussian to complex three dimensional models. The radionuclide concentration patterns are then projected into both external and internal dose patterns for use by the FRMAP organization in providing assessments to concerned State and local agencies.

The information provided by ARAC is valuable for planning the deployment of personnel, and available resources to the most effective locations. Full ARAC service requires extensive "customization" of information pertaining to a specific site, as well as developing the topographic files for use in ARAC calculations. In actual emergencies this service can be provided in about 1-4 hours in the absence of "customization". (See Appendix A of this document for more detailed discussion).

APPENDIX B – REFERENCES

[1] Code of Federal Regulations, Title 10 – Energy Chapter 1- Nuclear Regulatory Commission, Pt. 50, Appendix A, "General Design Criteria for Nuclear Power Plans."

[2] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plan and Environs Conditions During and Following and Accident," Rev. 2 (December 1980).

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[5] Ibid., U.S. Nuclear Regulatory Commission and Federal Emergency Management Agency.

[6] Ibid.

[7] U.S. Environmental Protection Agency, Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA-520/1-75-001 (September 1975). Also see U.S. EPA's Manual of Protective Actions for Nuclear Incidents, EPA-520/1-75-001A (January 1990).

[8] Ibid.

[9] Ibid.

[10] Ibid.

[11] Ibid.

[12] M.H. Dickerson, et. Al., Lawrence Livermore National Laboratory, ARAC Status Report: 1985, UCRL-53641 (May 1985).

APPENDIX C – CALCULATED RADIONUCLIDE PLUME CONCENTRATIONS AND RESULTING INHALATION DOSE

The Reactor Safety Study (RSS)[1] grouped accident sequences into sets called release categories, which were determined by the magnitude of the radioactive release and numbered accordingly, i.e., group 1 has the greatest release fraction and group 9 the least. The RSS designations for two example accidents are shown in Table C-l. The first accident presented in Table C-l is designated PWR 7 AHG-epsilon. The designations are those of the RSS. The PWR 7 signifies the release category for a pressurized water reactor while the letters signify a specific accident sequence. The AHG-epsilon sequence is a large loss of coolant accident (LOCA) with failure of the emergency core cooling system (ECCS) in the recirculation mode and failure of the containment heat removal system. Containment integrity is lost when the core melts through the containment base mat. The BWR 5 A accident is for a boiling water reactor in which the reactor coolant boundary is ruptured but all engineered safety features operate as designed.

In all of the accident scenarios reviewed in the RSS, the release of radioactive material to the environment will occur in several time segments, with different total amounts and mixtures of radionuclides being released during each time segment. In the examples shown, there are five discrete time segments for each accident, each with a different resultant plume concentration.

The plume concentrations shown in Table C-2 were calculated using the assumptions given in Regulatory Guides 1.3[2] and 1.4.[3] The assumptions are general in nature and are to be used in lieu of site specific data. Three different diffusion factors were used depending on the time of release, 0-8 hours, 8-24 hours, and 4-30 days. The diffusion factors, taken from the Regulatory Guides 1.3 and 1.4, were calculated on the following assumptions:

Table C-1. Description of Two Examples of Reactor Accident Sequences

See attachment for image – Table C-1

In order to evaluate the relative consequences of exposure from the airborne plume, the various plume concentrations shown in Table C-2 were converted to dose and the results are shown in Table C-3. Again, there are five discrete segments for each of the example accidents. This is due to the changing radionuclide concentration in the plume as the example accident proceeds. If an individual remained in the plume for the entire duration of the accident, the total dose would be a summation of the dose in each time segment.

The assumptions used in converting from plume concentration to dose were taken from Regulatory Guide 1.109.[4] The dose conversion factors and breathing rates were combined to establish the most highly exposed individual. Dose conversion factors (mrem/pCi) from Regulatory Guide 1.109 are higher for the infant and child than the teenager or adult. However, the teenager inhalation rate (0.91 m^3/h) is twice or more than that of infants (0.16 m^3/h) and children (0.41 m^3/h). More activity would be inhaled in the same time resulting in a higher dose to the teenager. The inhalation rates for the adult and teenager are the same but dose conversion factors for the teenager are higher, therefore, for the same amount of radioactivity inhaled, the result is a higher dose to the teenager. Because the teenager is indicated as the individual who would receive the highest dose from a given plume concentration examples are shown for the teenager as opposed to the infant, child or adult. The doses calculated are for exposure to the plume for the duration of the accident. Since the examples are intended to show the relative importance of the various radionuclides to dose, the duration of exposure is unimportant.

Table C-2. Calculated Airborne Plume Radionuclide Concentrations

See attachment for image – Table C-2 Part 1

See attachment for image – Table C-2 Part 2

See attachment for image – Table C-2 Part 3

See attachment for image – Table C-2 Part 4

See attachment for image – Table C-2 Part 5

Table C-3. Calculated Dose to Teenager from the Airborne Plume

See attachment for image – Table C-3 part 1
See attachment for image – Table C-3 part 2
See attachment for image – Table C-3 part 3
See attachment for image – Table C-3 part 4
See attachment for image – Table C-3 part 5

APPENDIX C – REFERENCES

[1] U.S. Nuclear Regulatory Commission, Reactor Safety Study, WASH1400, NUREG 75/015, Appendix V (1975).

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[3] U.S. Nuclear Regulatory Commission, Regulatory Guide 1.4, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Pressurized Water Reactors," Rev. 2 (1974).

[4] U. S. Nuclear Regulatory Commission, Regulatory Guide 1.109, "Calculations of Annual Dose to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I," (1977).

APPENDIX D – AIR MONITORING FOR RADIOIODINE

1. Introduction

Inhalation of radioiodine is typically expected to be the most important initial pathway of human exposure in the event of an airborne release of radioactivity during a nuclear power reactor accident. The thyroid gland would therefore be the critical organ and would receive the largest dose should an accident occur. Consequently, a method of monitoring for radioiodines in the presence of noble gas fission products, which can be released in much larger quantities than radioiodines and participate fission products, must be developed to provide a data base for evaluating or initiating protective action recommendations to control exposure to the population.

Costly measurement methods using gamma spectrometric analysis can be avoided by specifically sampling the air for radioiodine, and evaluating the radioiodine concentration through use of portable beta-gamma or gamma only detectors. The following is a discussion of procedures for use with generic types of equipment and instrumentation which are capable of meeting the radioiodine monitoring requirements set forth in Evaluation Criterion 1.9 of NUREG-0654,[1] i.e., 10^{-7} $\mu Ci/cm^3$.

2. Air Sampling System

The collection of an airborne radioactivity sample requires an air sampling system composed of two fundamental components: 1) an air mover, and 2) sample collection media. For the purpose of emergency response field monitoring, the air mover must be portable and it must have a reliable power supply. The sample collection media must have the ability to separate particulate and gaseous radioactivity and furthermore, the media must retain radioiodine and reject noble gases.

2.1 Air Mover.

A variety of direct current (DC) or alternating current (AC) portable air samplers are commercially available. As a minimum, these portable air samplers should meet the performance criteria found in ANSI N320-1979.[2] The air sampler flow rate must be calibrated with both the particulate and iodine filter media in place. The air samplers should have a flow rate in the range of one to five cubic feet per minute (1-5 cfm). Care must be taken to assure that the air sampler flow rate is adjusted to match the optimum flow rates specified by the manufacturer of the adsorbent filter media cartridge which is used. Filter collection/retention efficiency will decrease if the flow rate is too high.

The air sampler power supply must be dependable for field use. If an AC sampler is used, either a portable generator or a DC to AC power converter must be included in the field monitoring equipment kit. If a DC air sampler is used, it can be operated off of the battery of the field monitoring vehicle or a separate battery power supply.

Air samplers must remain functional over a wide range of temperature extremes. Certain models of air samplers have exhibited high failure rates when tested at low temperatures.[3] Therefore, the user should have assurance from the air sampler manufacturer that the air sampler will operate correctly under all expected temperature extremes for the geographic region.

2.2 Sample Collection Media.

One of the most important aspects of emergency air monitoring is the selection of the appropriate sample collection media. A HEPA type prefilter placed before an adsorber type filter medium cartridge can effectively separate the airborne radioactivity into iodine and particulate fractions. A small amount of elemental radio-iodine, if it is present, may adsorb on the particulate prefilter. However, the quantity of radioiodine on the particulate filter is expected to be small enough that it will not affect the protective action decision making processes which are based upon field monitoring team measurements.

Adsorption of fission product noble gases relative to radioiodine can be reduced by using an appropriate inorganic adsorber medium. Activated charcoal, an organic adsorber medium, is an efficient collector of radioiodine, but it also collects a significant portion of the radioactive noble gases. This property makes the charcoal adsorber medium unacceptable for use with simple operating gross radiation measurement instrumentation. At this time, there are three commercially available types of inorganic adsorber media. These are silver zeolite, silver silica gel,[4] and silver alumina. Tests of these adsorbent media have indicated that silver zeolite and silver alumina have the lowest retention (highest rejection) efficiency for noble gases, followed by silver silica gel.[5] However, there appears to be considerable variability in noble gas retention efficiency both within and between types of adsorber media. The sources of this variability appear to be related to the vendors, method of preparation, and environmental conditions, such as humidity, based on test data.[6] Therefore, it is recommended that the users of the inorganic adsorber media obtain quality assurance test certificates from the vendors which specify adsorber noble gas retention efficiency with respect to sampler flow rate and environmental conditions such as relative humidity and temperature. These quality assurance test certificates should be obtained for each type of adsorber medium and each new production batch within a given type of adsorber medium.

Retention of radioiodines on both the organic and inorganic adsorber media appears to be greater than 90%.[7] Silver silica gel appears to have the lowest radioiodine retention efficiency, whereas, both silver alumina and silver zeolite have higher radioiodine retention efficiencies, approximately 99.9%.[8]

The silver silica gel adsorber medium is in an activated, dry, form. Both the silver zeolite and the silver alumina media are deactivated, i.e., they contain some moisture. Tests indicate that the radioiodine retention efficiency of the silver silica gel adsorber medium is reduced when an air sample is collected under environmental conditions where there is high relative humidity. The radioiodine retention efficiency of the silver zeolite and the silver alumina adsorber media was not affected as much as the silver silica gel by the increase in relative humidity. Therefore, it appears that the silver zeolite and the silver alumina media would be more useful than the silver silica gel medium in geographic areas which routinely have a high relative humidity.

3. Field Radiation Counting Instruments

The radiation detection instruments used for gross field measurements of the particulate air filters and the radioiodine adsorbent media cartridges can be either simple count rate instruments or instruments with integrating circuitry which are capable of accumulating sample counts over a preset time period. More complex multichannel analyzer systems are not recommended for emergency field monitoring use. (See Appendix E for instrument performance specifications.)

3.1 GM Detectors.

Standard thin window, e.g., 1.4 to 2.0 mg/cm^2, pancake type GM detectors may be used for counting both the particulate filters and the adsorber medium cartridges. Pancake type GM detectors are available through most commercial instrument vendors, e.g., Eberline, Ludlum, Victoreen, and others. The pancake type detector configuration is recommended, since the detector surface area closely corresponds to the surface collection area of commercially available particulate filters and adsorber media cartridges. A sample holder for the particulate and adsorber medium filters is recommended to provide a reproducible sample to detector counting geometry.

The pancake GM detector counting efficiency for I-131 collected on adsorber media cartridges is approximately 5400 counts per minute per microcurie (5400 cpm/μCi) or approximately 0.0025 counts per disintegration.[9] Individual radiation detection instruments should be calibrated for the radionuclides expected to be present in the sample. (As a minimum, the accident assessment personnel must be aware of any nonlinear energy response characteristics that the GM detector may have. For example, the pancake GM detector has a significant over response at gamma energies in the 80 keV range, i.e., those gamma energies associated with I-131 and Xe-133. The special GM detector utilized in the Distenfeld[10] air sampling system has a significant over response at higher gamma energies, i.e., those gamma energies associated with I-132.)

For radioiodine, there are several isotopes (I-131, I-132, I-133, I-134, and I-135) that will be present depending on the time after reactor shutdown at which the sample is collected (see Figure D-l). The amount of I-132 present in the radioiodine mixture is particularly noteworthy, because the amount of I-132 is influenced both by the time of sample collection following reactor shutdown and by the time of sample collection following release from containment (see Figure D-l). With respect to the total amount of radioiodine following release from containment, Figure D-l is but one representation from a family of curves that are dependent upon the time after reactor shutdown that a release begins.

An air sample's gross count rate may be very much affected (increased) by these short-lived isotopes which will be present in air samples containing fresh fission product gases (see Figure D-2). These short-lived radionuclides may not contribute significantly to the potential radiation dose, but they will affect the sample's gross count rate. There is a potential for error if the sample count rate is not appropriately adjusted prior to making protective action recommendations based on the air sample data.[a] (However, any error introduced by uncorrected gross GH detector measurements will be conservative, i.e., higher than actual concentrations of 1-131 will be indicated.) The instrument users should develop correction curves for instrument response vs. time after reactor shutdown and time after release that the sample is collected and counted. Information on the reactor core inventory of these radioiodine isotopes may be obtained from the Reactor Safety Study document.[11]

[a] There are some types of postulated accidents where these corrections do not apply, i.e., steam generator tube leaks.

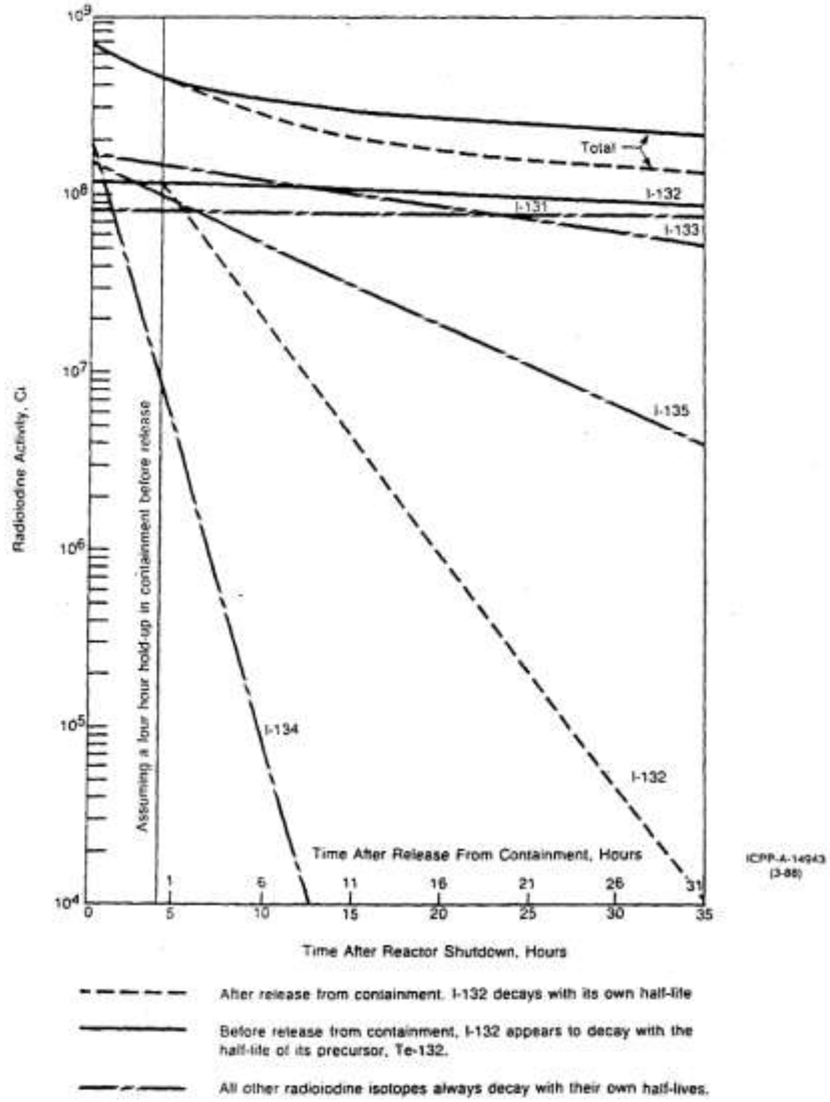

Figure D-1. Radioiodme Activity vs. Time after Reactor Shutdown and Time after Release from Containment. Eased on a 3200 Megawatt Thermal (1000 MWe) Reactor with Core al Equilibrium

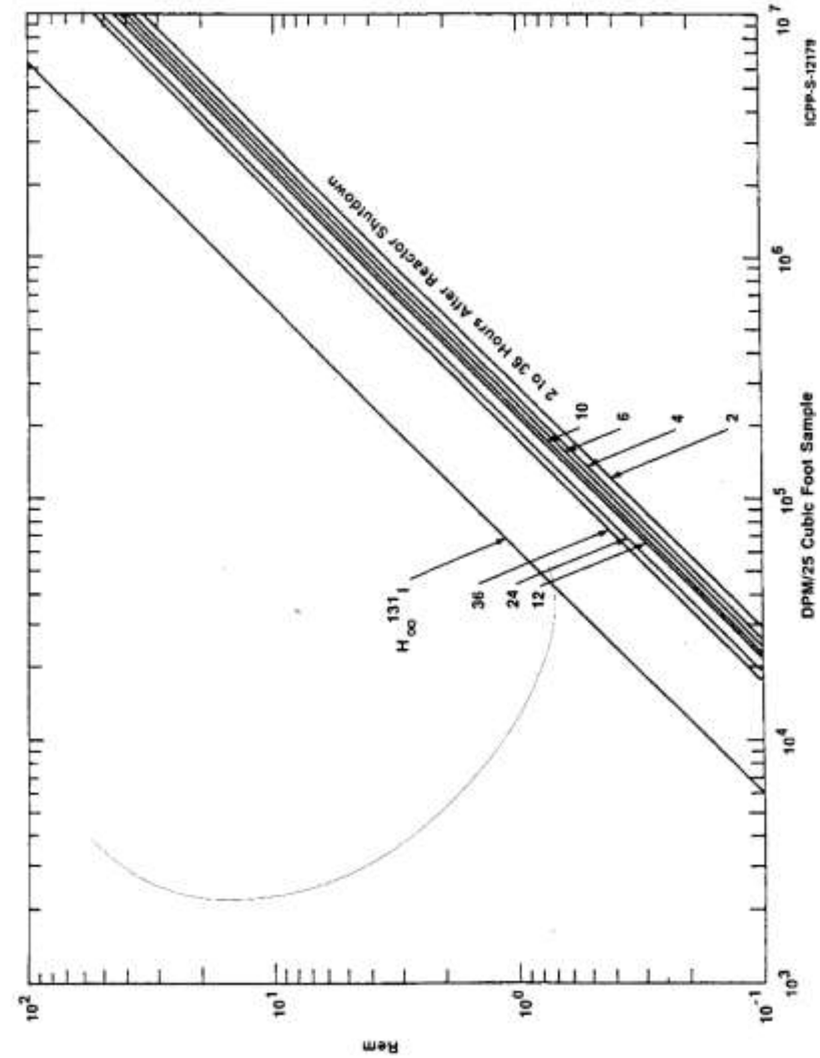

Figure D-2. DPM/25 Cubic Foot Sample
Radioiodine Activity in a Child's Thyroid vs. Dose Commitment for a 10 hour Exposure
{Derived from data contained in References 4 and 6)

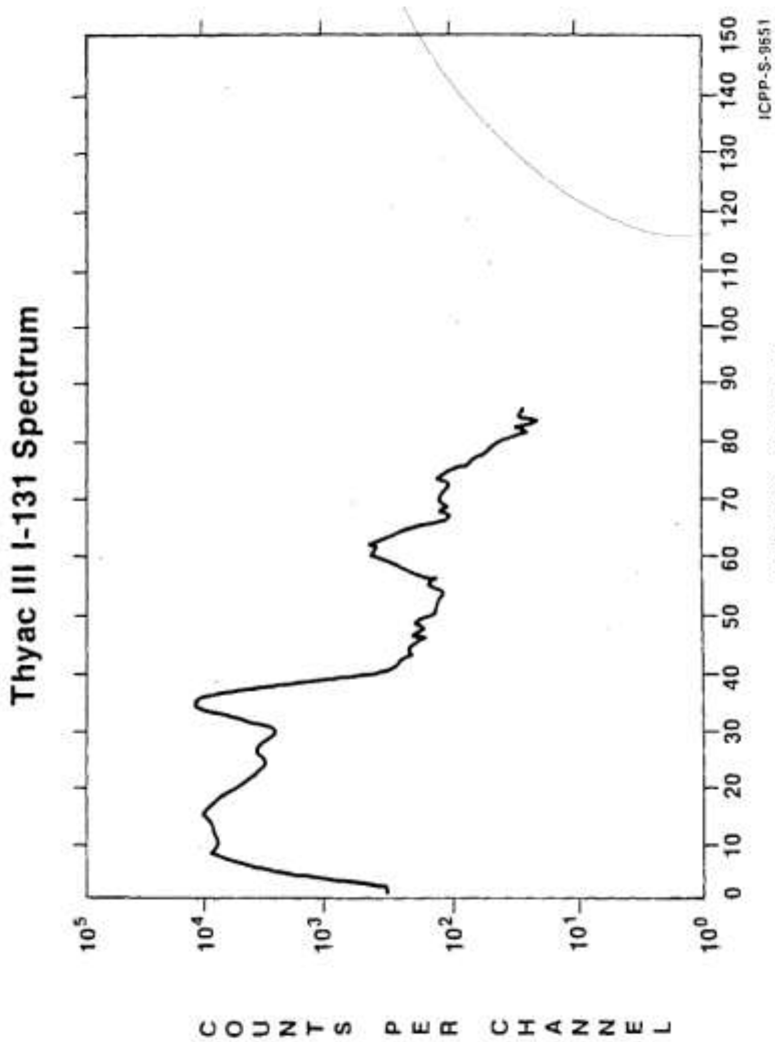

Figure D-3. Thyac III 1-131 Spectrum Hand-Held 1.25" x 1.5" NaI(T1) Spectrum of 1-131 at 10 keV/Channel

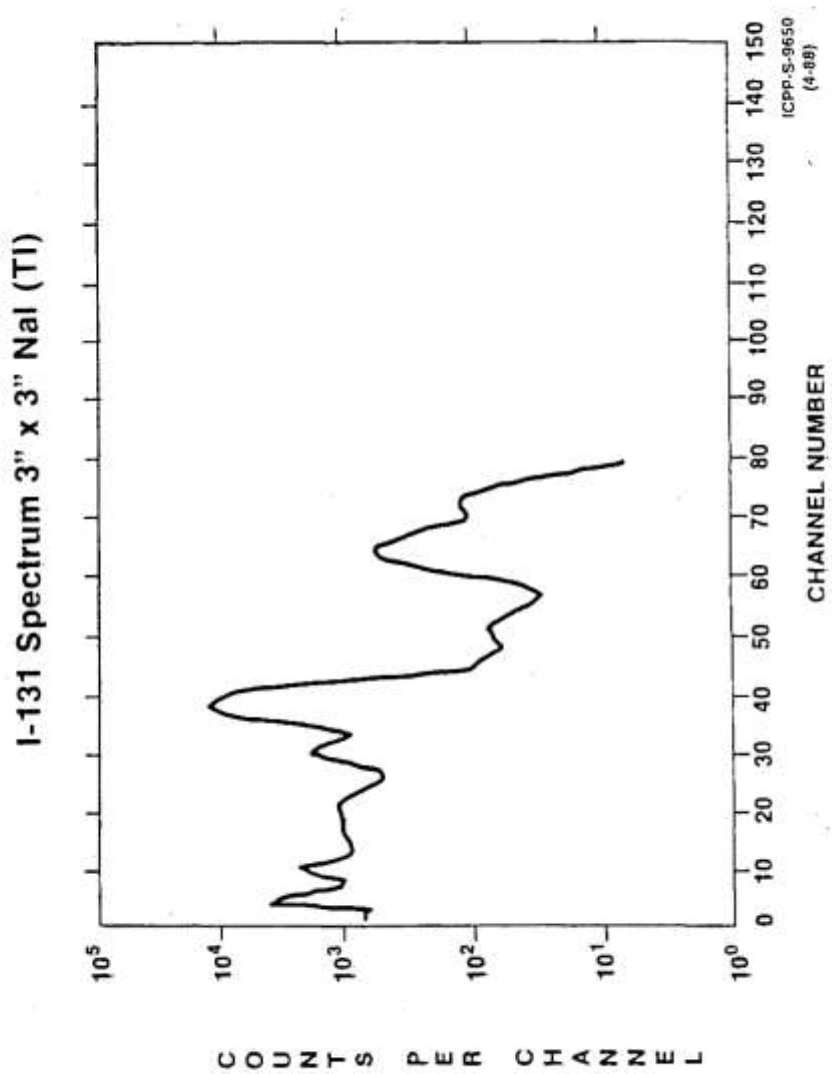

Figure D-4. 1-131 Spectrum 3" x 3" NaI (Tl) 3" x 3" NaI(T1) Spectrum of I-131 at 10 keV/Channel

3.2 NaI (Tl) Detectors.

Standard l" x l" or 2" x 2" portable NaI(Tl) detectors may be used with gross count rate meters, single channel analyzers, or dual channel analyzers to provide a more sensitive means of detecting radioiodine on the adsorber medium cartridges or gross radio activity on the particulate filters. The user must be aware of the limitations of these portable NaI(Tl) detector systems. The more complex system, e.g., dual channel analyzer, does not necessarily provide a more sensitive means of measuring the quantity of I-131 contained in the adsorber medium cartridge. The reason for this is that the smaller portable NaI(Tl) detectors do not have as good a spectral response as the larger laboratory size, e.g., 3"x3" or larger, detectors. Figures D-3 and D-4 show the I-131 spectral response of 1.25" x 1.5" and 3"x3" NaI(Tl) detectors, respectively. From these figures, it can readily be determined that the smaller size NaI(Tl) detectors have less resolution and much lower peak to Compton continuum ratios than the larger size NaI(Tl) detectors. These qualities may lead to errors in data interpretation.

For example, if a small l"x l" or 2"x2" NaI(Tl) detector is used with a single or dual channel analyzer which is set at the I-131 energy, there will be a significant number of counts appearing in the 1-131 channel due to the presence of the other higher energy short-lived isotopes of radioiodine, if there is any fresh fission product radioiodine in the sample. These additional counts in the 1-131 channel will be due to the Compton continuum contribution of the higher energy radionuclides. This presents a serious complication for the use of the dual channel analyzer. Since the dual channel analyzer utilizes a background subtraction technique, there is a good chance of over subtraction of background counts and thus an underestimation of the counts in the 1-131 channel. This could lead to an underestimation of the I-131 concentration in air. Therefore, the user should develop detector response curves for adsorber medium cartridges counted at varying times after reactor shutdown or after release from containment.

3.3 Instrument Sensitivity.

The sensitivity or minimum detectable level (HDL) of an instrument is a function of the uncertainty of the instrument's background count rate. For instruments with analog readouts, the MDLs in counts per minute (cpm) may be calculated from the equation:[12]

$$MDL = 2\sqrt{\frac{B}{2RC}}$$

Where B is the background count rate in cpm and RC is the meter time constant in minutes given by the manufacturer. For instruments with digital readout displays, the MDL may be expressed by the equation:

$$MDL = 2\sqrt{B}$$

Where again, B is the background count rate in cpm.

Using the MDL equation, the ability for an instrument to detect radioiodine at a concentration of 10^{-7} µCi/cm^3 can be estimated. The minimum detectable air sample concentration may be expressed as follows:

$$C = MDL/VCY$$

where: C = concentration of µCi/cm^3

$MDL = 2\sqrt{\frac{B}{2RC}}$ or $2\sqrt{B}$ in cpm

V = sample volume in cm^3

CY = instrument counting yield in cpm/µCi

The following is an example calculation using assumptions which are reasonable for a pancake type GM detector.

B = background count rate of 600 cpm

RC = instrument time constant of 5 seconds

$V = 10\ ft^3 = 2.832x10^5\ cm^3$
CY = 90 cps/μCi pf I-131 = 5400 cpm/μCi

$$c = \frac{2\sqrt{\frac{\frac{600\ cpm}{2x5\ sec}}{60\ sec/min}}}{2.832x10^3\ x\ 5.4x10^3\ cpm/\mu Ci} = 7.85x10^{-8} \mu Ci/cm^3$$

Thus it can be shown that, if properly handled, relatively simple counting instrument systems are capable of meeting the instrument sensitivity requirements of NUREG-0654.[13]

4. Emergency Response Monitoring for Radioiodine

Air sampling for radioiodine should be done at locations determined by the Emergency Operations Center (EOC) field team coordinator (FTC). The FTC should determine the air sampling locations from the open and closed window exposure rate measurements which are continually being made by the field monitoring teams. An air sample collected at a location where both the closed and the open window measurements indicate that the detector is in the plume, e.g., an elevated closed window reading and an open window reading which is significantly higher than the closed window reading, should be representative of the plume composition. The rationale for this procedure is that the air samples must be knowingly taken from within the plume, not from locations which are off to the side or underneath of the plume, in order to obtain useful information about the radioiodine concentration. The converse is true if background air samples are requested from areas outside of the plume.

There is not a set number of air samples that can be specified for a given emergency. There are, however, some basic criteria that need to be observed during all emergencies which have an offsite release of radioactivity. These criteria are: 1) some of the air samples must be taken from within the plume near plume centerline, and 2) the ALARA principle must be applied to the field monitoring team personnel to minimize their exposure, e.g., this may require reduced sample collection times, moving to a location further downwind where exposure rates are lower, or use of protective equipment or radioprotective drugs.

4.1 A Generic Radiodine Air Monitoring Procedure

The first field monitoring step is to proceed to the sampling area designated by the FTC. Then traverse the plume using survey instrumentation to determine the plume centerline if the sample is to be taken at or near the plume centerline. At the sampling location, attach a filter holder, containing a particulate filter and adsorber medium cartridge, to a calibrated air sampler. The air sampler should be positioned upwind from any motor exhaust and preferably off the ground far enough to avoid extraneous sources of particulate matter. A minimum sample volume of 10 cubic feet should be collected, e.g., sample at a flow rate of 2 cubic feet per minute for 5 minutes.[b] After the air sample has been collected, the field monitoring team should immediately move to a low background location outside of the plume. At this location, the adsorber medium

[b] Other floe rates and sampling times may be used, however, the user must be aware of the limitations of the adsorber media and choose the optimum sampling conditions, e.g., the adsorber collection efficiency decreases with an increase in flow rate.

cartridge should be purged and both the particulate filter and adsorber cartridge should be counted.[c] The sample count rate data should be relayed by the field monitoring team to the EOC dose assessment group. Both the particulate filter and the adsorber medium cartridge must be packaged (placed in a plastic bag), labeled, and taken to a laboratory for a more sophisticated counting procedure to verify the field measurements. It should be noted that NaI detectors will not detect the presence of pure beta emitters such as strontium-90. However, if the particulate air filters are taken quickly to a laboratory and analyzed on a NaI or GeLi detector, the short-lived gamma emitting strontiura-91 isotope can be detected and this will give an indication of whether or not strontium-90 is present in the air sample. Also, if the strontium—90 concentration on the particulate filter is high, there will be a significant amount of Bremsstrahlung (x-rays) which will be detected by the laboratory instruments. Figure D-5 is an example of the type of information that should be included on the label for the air sample.

[c] Purging refers to passing "clean" air through the adsorber medium cartridge to remove fission product noble gases which are entrained in the void spaces within the adsorber medium. These noble gas molecules are not attached to the adsorbent medium and they are easily removed by passing a few void volumes of clean air through the cartridge. The purge may be accomplished by simply turning the air sampler on for a few seconds, or if there is a concern about the effects of naturally occurring radon, a simple purging apparatus can be made which utilizes a small cylinder of aged compressed air as the purge air supply. Purging the adsorber medium cartridge can reduce the percentage of retained noble gases by a factor of 50 or more (See reference 8).

LOCATION WHERE AIR SAMPLE IS TAKEN______________________________________
____

NAME OF PERSON TAKING SAMPLE____

TIME AT WHICH AIR SAMPLE IS COLLECTED (START)__________ (STOP)___________

VOLUME OF AIR SAMPLE_________________ FLOW RATE____________

AIR SAMPLE PUMP IDENTIFICATION NUMBER.___________________________________

DATE________________________

<u>AREA RADIATION MEASUREMENTS</u>

RADIATION DETECTOR IDENTIFICATION NUMBER_____________________________

OPEN WINDOW READING AT 3' ABOVE GROUND____________________C/M

CLOSED WINDOW READING AT 3' ABOVE GROUND______________C/M OR MR/H

OPEN WINDOW READING AT 3" ABOVE GROUND________________C/M

CLOSED WINDOW READING AT 3" ABOVE GROUND _____________C/M OR MR/H

______ ______ ______ ______ ______ ______ ______

EVALUATION

LOCATION WHERE EVALUATION IS MADE_____________________________________

RADIATION DETECTOR IDENTIFICATION NUMBER____________

BACKGROUND READING____C/M

ADSORBER CARTRIDGE ____ C/M

PARTICULATE FILTER____ C/M

TIME OF READOUT - BEGINNING______________ ENDING ___________________

DATE ____

NAME OF PERSON MAKING EVALUATION_______________________________. ___

Figure D-5. Air Sample Particulate Filter-Absorber Cartridge Lab

APPENDIX D- REFERENCES

[1] U.S. Nuclear Regulatory Commission and Federal Emergency Management Agency, Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, NUREG-O654/FEMA-REP-1, Rev. 1 (November 1980).

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[7] Ibid., S.A. McGuire et al.
C. A. Pelletier, "Behavior and Measurement of Radionuclides in Effluents and the Environment," presented at the Professional Enrichment Program of the 1984 Annual Health Physics Society Meeting, New Orleans, Louisiana (June 8, 1984).

[8] Ibid., C. A. Pelletier.

[9] Ibid.

[10] Ibid., C. Distenfeld and J. Klemish.

[11] U. S. Nuclear Regulatory Commission, Reactor Safety Study. App. VI, WASH 1400/NUREG 75-014 (1975).

[12] J. F. Krupa, S. K. Bird, and B. G. Motes, Evaluation of Portable Instruments for Emergency Response Measurement of Radioiodine, NUREG/CR-2267, WINCO-1003 (March 1984).
[13] Ibid., U. S. Nuclear Regulatory Commission and Federal Emergency Management Agency.

APPENDIX E – PORTABLE EMERGENCY MONITORING INSTRUMENTATION AND EQUIPMENT SPECIFICATIONS

1. Introduction

This appendix provides references to American National Standards Institute (ANSI) documents which contain specifications and calibration requirements for portable radiological survey instruments, portable air samplers, direct reading dosimeters, and indirect reading dosimeters. The Plume Exposure Rate Verification System and the Emergency Worker Radiation Exposure Monitoring System should be composed of combinations of radiation monitoring instruments and equipment which meet ANSI requirements. Although some of the referenced ANSI documents are directed toward on-site emergency response instrumentation and equipment, the requirements which apply to portable instrumentation and equipment can be equally well applied to off site emergency response instrumentation and equipment. ANSI specifications are continuously updated and/or reaffirmed. Therefore, the latest issuance of the specification should be used.

2. Portable Radiological Survey Instrumentation

The instrumentation for exposure rate or count rate measurements should meet the requirements of ANSI N320-1979.[1] The instrument testing procedures, e.g., procedures for determining system accuracy, spectral and angular dependence, temperature influences, other environmental influences, exposure rate limitations, etc., should conform to ANSI N13.4-1972.[2]

3. Portable Air Samplers

The air mover, e.g., the pump, and the sample filter holder unit of the portable air sampling system should meet the portable air sampler requirements of ANSI N320-1979.[3]

4. Calibration of Portable Emergency Radiation Monitoring Instrumentation

Calibration of portable radiation detection instruments involves routine testing of certain radiological characteristics of the instruments. These tests should be repeated routinely on at least an annual basis because aging of components and batteries or replacement of components may affect the calibration. One precalibration and primary calibration requirements and the calibration frequency for linear, logarithmic, and digital readout instruments should meet N328-1978[4] requirements

5. Direct Reading Dosimeters

The emergency worker's direct reading dosimetric devices should be adequate to measure exposures as low as 0.5 R, as well as measure exposures in the range of. the most reasonably expected preplanned exposures and measure possible accidental exposures that might be received in excess of the preplanned limits. If possible, the dosimeters should also measure in excess of the emergency lifesaving protective action guide[5] of 75 rem. In order to meet this exposure range criteria, two direct reading dosimeters may be required to provide adequate sensitivity and the range of exposure coverage. These direct reading devices should be direct reading quartz fiber dosimeters with overlapping ranges, a 0-5 R dosimeter or 0-20 R dosimeter in conjunction with a dosimeter with a range of at least 0-100 R. The 0-5 or 0-20 R direct reading dosimeter will provide adequate sensitivity to read radiation mission exposures in the 5 R range or less to determine compliance with the emergency worker's protective action guide for whole body exposure[6] as specified in Evaluation Criteria K.4 of NUREG-0654.[7] Direct reading dosimeters with ranges of 0-100 R or 0-200 R are commonly available and provide an exposure range which measures exposures in excess of the lower range dosimeter and is adequate to measure accidental radiation exposures or radiation exposures which may reach the 75 rem life saving protective action guide. The direct reading dosimeters should meet the requirements and the inspection and test specifications of ANSI N322-1977[8]. The direct reading dosimeters and the dosimeter chargers relationships should inset the requirements of ANSI N42.6-1980.[9] Dosimeters should be routinely tested for electrical leakage and calibrations as recommended in Section 4.

6. Indirect Reading Dosimeters

Indirect reading dosimeters should be used to provide a record of the emergency worker's integrated exposure over an entire accident. The indirect reading dosimetry system should preferably utilize thermoluminescent dosimeters, although film, glass bulb, or other similar types of indirect reading dosimeters and their associated readout devices could be acceptable. The hardcopy of the readouts from the indirect reading dosimeters should be kept as a part of the permanent file record of the emergency worker's exposure.

The suppliers of indirect reading dosimetry services should meet the performance test criteria of ANSI N13.11-1983[10] and the dosimstry processors should also be accredited by the National Bureau of Standards (NBS), Office of Product Standards Policy program for evaluating personnel dosimetry processing, the National Voluntary laboratory Accreditation Program (NVLAP).

NVLAP accreditation is based on a process that includes five basic steps; application, proficiency testing, on-site assessment, evaluation and accreditation. Two steps, proficiency testing and on-site assessment form the technical basis of the accreditation.[11]

Accreditation in the Dosimetry laboratory accreditation program (IAP) is awarded for a period of two years after which the participant must apply for renewal. Both the on-site assessment of the processing facilities and proficiency testing are performed on the same two year cycle. Proficiency testing is conducted in accordance with ANSY N13.11 which defines eight radiation test categories.[12]

Dosimetry accreditation is limited to those types or models of dosimeters which document whole body and skin dose. Processors may gain accreditation for as many different dosimeter models or types as they wish, provided that they demonstrate ability to meet the criteria. The program is not applicable to extremity dosimeters, pocket ionization chambers, or environmental monitors.[13]

Table E-l shows the eight radiation test categories with radiation ranges and tolerance levels for deep and shallow dose equivalent as defined in ANSI N13.11-1983.[14] The FRPCC Subcommittee recommends that, for radiological emergency response purposes, the dosimetry processors meet test categories I, II, IV, V and VII during the NVLAP accreditation process. The NVLAP accreditation must be for the specific type of dosimetry in use, and must be for the type of radiation or radiations for which the individual wearing the dosimeter is monitored. Dosimetry users are advised to obtain an NBS annual directory[15] of NVLAP accredited laboratories to obtain information about each dosimetry processor's accreditation status and scope of accreditation.

Table E-l. Dosimeter Test Categories, Irradiation Range, and Tolerance Levels[8]

	Test Category	Test Irradiation Range	Tolerance Level (L) Deep	Shallow
I.	Accidents, low-energy photons (NBS technique MFT)	10 to 500 rad	0.3	No test
II.	Accidents, high-energy photons (Cs-137 gamma radiation)	10 to 500 rad	0.3	No test
III.	Low-energy photons (NBS techniques IG, II, IK, MFC, MPG, MFI)	0.3 to 10 rem	0.5	0.5
IV.	High-Energy photons (Cs-137 gamma radiation)	0.3 to 10 rem	0.5	No test
V.	Beta Particles (Sr-90/Y-90)	0.15 to 10 rem	No test	0.5
VI.	Photon mixtures (Any combination of categories III and IV)	0.05 to 5 rem	0.5	0.5
VII.	Mixtures, photons and beta particles (Any combination of categories IV and V)	0.20 to 5 rem	0.5	0.5
VIII.	Mixtures, Cf-252 fission neutrons, moderated by 15 cm of D O covered with cadmium and high-energy photons (category IV)	0.15 to 5 rem	0.5	No test

APPENDIX E – REFERENCES

[1] American National Standards Institute, Standard N320-1979, "American National Standard Performance Specifications for Reactor Emergency Radiological Monitoring Instrumentation."

[2] American National Standards Institute, Standard N13. 4-1971, "American National Standard for the Specification of Portable X- or Gamma-Radiation Survey Instruments."

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[5] U.S. Environmental Protection Agency, Manual of Protective Actions for Nuclear Incidents, EPA-520/1-75-001A (January 1990).

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