Guidance on Offsite Emergency Radiation Measurements Systems Phase 3: Water and Non-Dairy Food Pathway

FEMA-REP-13

May 1990

FEMA

Guidance on Offsite Emergency Radiation Measurement Systems

Phase 3 - Water and Non-Dairy Food Pathway

Developed by:
Westinghouse Idaho Nuclear Company, Inc.
Idaho National Engineering Laboratory

Funded by:
Federal Emergency Management Agency
Under DOE Contract No. DE-AC07-84ID12435

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

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18948

FEDERAL EMERGENCY MANAGEMENT AGENCY

FEMA REP-13, Guidance on Offsite Emergency Radiation Measurement Systems, Phase 3—Water and Non-Dairy Food Pathway

AGENCY: Federal Emergency Management Agency (FEMA).

ACTION: Notice of availability of a FEMA guidance document on offsite emergency radiation systems for measurement of the potential radiation dose to the public through the water and non-dairy food pathway in the event of an accident at a commercial nuclear power plant and invitation for comments on the guidance document.

SUMMARY: The document, "Guidance on Offsite Emergency Radiation Measurement Systems, Phase 3—Water and Non-Dairy Food Pathway", FEMA REP-13, dated May 1990, will be

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available for public distribution and comment on May 31, 1990. Copies will be distributed to State, local governmental and utility emergency planners with nuclear power plant planning and preparedness responsibilities and to member agencies of the Federal Radiological Preparedness Coordinating Committee for review, comment, and interim use.

As the lead Federal Agency under the FEMA rule 44 CFR part 350, FEMA is responsible for the approval of offsite radiological emergency planning and preparedness around commercial nuclear power plants throughout the United States. This rule provides the regulatory framework through which the Agency evaluates and approves State and local radiological emergency planning and preparedness. Under the FEMA rule 44 CFR part 351, FEMA provides guidance to State and local governments such as FEMA REP-13. This document was developed to elaborate upon the planning standards and evaluation criteria of NUREG-0654/FEMA REP-1, Rev. 1, "Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants" and 44 CFR part 350 as related to offsite emergency radiation systems for measurements in the water and non-dairy food pathway. The guidance is intended to assist State, local and utility radiological emergency planners in developing and enhancing radiological emergency planning and preparedness and for FEMA and other Federal agencies to use in evaluating the adequacy of offsite emergency radiation systems for measurement in the water and non-dairy food pathway.

FEMA REP-13 is the third in a series of guidance documents on offsite emergency radiation measurement systems prepared by the Federal Radiological Preparedness Coordinating Committee, Subcommittee on Offsite Emergency Instrumentation for Nuclear incidents. This document provides guidance on the selection and use of radiation instrumentation and methodologies that are currently available for detecting and measuring radioactive contamination, in the event of a nuclear accident at a commercial nuclear power plant, with emphasis on the measurement and evaluation of radionuclides in potable water and non-dairy food to determine the dose commitment to individuals.

The radionuclide concentrations warranting emergency actions for potable water and edible plants are derived from the Food and Drug Administration (FDA) protective action guides. Protective actions and monitoring requirements are discussed in the document. Several alternatives for field monitoring of foodstuffs and water are also presented. However, the recommended procedure for monitoring foodstuffs is field sampling in predetermined areas followed by laboratory analyses. The recommended procedure for monitoring water is collection of samples at water purification plants followed by analyses performed by expereinced technical personnel. Protective action levels recommended by the FDA for water and non-dairy foods are used as the basis for monitoring requirements outlined in FEMA REP-13. Early monitoring will provide data to prevent significantly contaminated water and foods from being processed and distributed and will provide the basis for the most timely emergency response action.

This document is intended for interim use pending publication of a final edition. Comments received by FEMA on this document will be analyzed by the Federal Radiological Preparedness Coordinating Committee, Subcommittee on Offsite Emergency Instrumentation for Nuclear Incidents, and the results of this analysis will be used to develop the final edition of FEMA REP-13. A single copy of this document may be requested by writing FEMA, P.O. Box 70274, Washington, DC 20024. Please request FEMA REP-13, "Guidance on Offsite Emergency Radiation Measurement Systems, Phase 3—Water and Non-Dairy Food pathway".

Comments on this document will be accepted through September 30, 1990, and should be addressed to: Rules Docket Clerk, Federal Emergency Management Agency, room 835, 500 C Street Southwest, Washington, DC 20472.

Dated: April 27, 1990.

For the Federal Emergency Management Agency.

Grant C. Peterson,

Associate Director, State and Local Programs and Support.

[FR Doc. 90-10542 Filed 5-4-90; 8:45 am]

BILLING CODE 6718-20-M

PREFACE

This document is intended for use by Federal, State, and local officials who are responsible for radiological emergency preparedness. This document is the third of a series on guidance on offsite emergency radiation measurement systems. It has been prepared by the Federal Radiological Preparedness Coordinating Committee (FRPCC), Subcommittee on Offsite Emergency Instrumentation for Nuclear Incidents. Extensive guidance by the various subcommittee members has been incorporated into this document. The Food and Drug Adminstration (FDA) is currently considering the revision of their recommended food protective action guides (PAGs). However, any revisions are not expected to impact on the general guidance on the type of instrumentation required or the type of samples that will be required to be taken. Any impact is anticipated to be a simplification of the radionuclide measurement procedures for implementing the FDA PAGs. Therefore, it is being published by FEMA now because of the need by State and local governments for the type of information and guidance contained in this document.

An earlier version of this document was issued on a preliminary basis as a technical report, WINCO-1012, in October 1984 by the Westinghouse Idaho Nuclear Company Inc., Idaho National Engineering Laboratory for interim use and comment. The May 1990 edition of FEMA REP-13 replaces WINCO 1012 and all earlier drafts of REP-13 which should no longer be used.

All comments received to date on WINCO 1012 and earlier drafts of FEMA REP 13 have been considered in the May 1990 publication of FEMA REP-13, which is issued for interim use and comment. Comments are encouraged for consideration by the FRPCC Subcommittee prior to FEMA's publishing FEMA REP-13 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.

The Federal Register notice of May 7, 1990, Vol. 55, No. 88, pages 18948 and 18949, requested comments on this document by September 30, 1990. However, the comment period has been extended and comments will be accepted through December 31, 1990.

ABSTRACT

This document provides guidance to State and local governments and to Federal agencies on offsite emergency measurement of radionuclides in non-dairy food and potable water to determine dose commitment after a major accident involving a light-water nuclear power plant. The monitoring and controlling of fresh milk would be the primary concern for the ingestion pathway and separate guidance has been provided in an earlier document titled, "Guidance of Offsite Emergency Radiation Measurement Systems, Phase 2 - The Milk Pathway". The radionuclide concentrations warranting emergency actions for potable water and edible plants are derived from Food and Drug Administration (FDA) protective action guides.

In the early emergency phase of an accident, monitoring of the ingestion pathway should be primarily directed toward controlling the human ingestion of deposited airborne contamination. Ingestion of edible plants is the non-dairy food pathway of primary concern. The importance of this pathway would be dependent on the time of the year the nuclide release occurred, e.g., deposition of radionuclides on plants just prior to or during harvest presents the greatest hazard. The meat pathway, in comparison, is dependent on the plant and water pathway and is, therefore, not considered for monitoring during the early emergency phase of an accident.

The greatest immediate concern following a release may be from the radioiodines. However, because of their short half-life, the hazard would diminish rapidly and the longer half-life radionuclides of strontium and cesium would become important. Protective actions and monitoring requirements are discussed. Several alternatives for field monitoring of foodstuffs and water are presented. However, the recommended procedure for monitoring foodstuffs is field sampling in predetermined areas, followed by laboratory analyses. The recommended procedure for monitoring water is collection of samples at water purification plants followed by laboratory analyses performed by experienced technical personnel.

SUMMARY

This document provides guidance to Federal, State, and local officials on the selection and implementation of an emergency radiation monitoring system to determine the potential radiation dose to the public from the potable water and non-dairy food pathway in the event of an accident at a light-water nuclear power plant. Information from a monitoring system should provide the technical basis for protective actions to preclude consumption of seriously contaminated water and non-dairy foodstuffs.[a] Therefore, plans to implement the emergency monitoring system should be completed prior to the occurrence of an accident at a nuclear power plant. Methods useful for the development of an emergency monitoring plan are discussed. Resources required for implementing this system are described. Identification of the nuclides of concern, the appropriate instrumentation, and the monitoring options and their associated problems are essential to the development of an effective emergency monitoring plan for the water and non-dairy food pathway.

When planning an emergency radiation monitoring system, two principal considerations are: 1) that under field conditions, only gross radiation measurements will be used to determine emergency or nonemergency conditions; and 2) the instrumentation used must be reliable, simple to operate, durable, yet sufficiently sensitive. For nonemergency conditions or subsequent confirmatory analyses, better and more sophisticated instrumentation should be available for use under controlled laboratory conditions. The radiation detection instrument sensitivity requirements are dependent upon: 1) the energy and type of radiation to be measured; 2) background radiation levels; and 3) the derived response levels (i.e., radionuclide concentration) being measured. These derived response levels correspond to the preventive and emergency Protective Action Guide (PAG)

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[a] All materials are, and always have been, radioactive so the safety objective is to limit the intake of <u>seriously</u> contaminated foodstuffs.

projected dose commitments of 1.5 and 15 rem to the thyroid and 0.5 and 5.0 rem to the whole body, bone marrow, or any other organ, respectively.

There has never been a major release of radioactivity from a commercial operating U.S. nuclear power plant so release estimates must be based on models. Using the existing Reactor Safety Study (RSS) accident scenarios and associated source term releases, radioiodines have been identified as the radionuclides of major concern with respect to potential projected dose commitment from ingestion of contaminated water and foodstuffs immediately following an accidental release of radioactivity. The accident source terms are currently being reevaluated and will probably result in lower assumed radioiodine release rates. However, radioiodine will still remain an important parameter to measure during the initial emergency response sampling and monitoring because of the potentially high release rates and high deposition velocities. For the long-term (weeks to months following the radioactive release) the long half-life radionuclides may become the major concern with respect to projected dose commitment. Based on foodstuff ingestion rates and dose conversion factors, the child has been identified as the critical segment of the population for the non-dairy food pathway. However, for the water pathway, the infant is the critical segment of the population.

Ability to monitor potentially contaminated samples at or below the derived preventive response level would be essential for providing the decision makers with the necessary information to take the correct protective actions, i.e., divert or condemn contaminated water and food supplies. Therefore, a number of field monitoring instruments (ratemeters with 1.25"x1.5" NaI(Tl) or GM detector probes) were evaluated. All of the evaluated instruments were sensitive enough for field monitoring at the emergency derived response levels. However, for water, only the instruments with the 1.25"x1.5" or larger NaI(Tl) detectors were found to be practical and sensitive enough for field monitoring at the preventive derived response levels.

Various water sample/detector counting configurations were evaluated: monitoring the outside of the sample container; immersion of the detector in the container; and monitoring samples concentrated via ion exchange resin. Based on these evaluations, the immersion method and the ion-exchange method appear to be sufficiently sensitive for field monitoring at the preventative derived response levels. The instruments evaluated did not have adequate sensitivity for detecting derived preventive response levels by monitoring the outside of the sample container. The immersion method requires a 20 liter sample volume whereas the ion exchange method requires a 3-4 liter sample volume. The ion exchange method also has some advantages with respect to sample preservation and storage for subsequent confirmatory analyses under controlled laboratory conditions.

For emergency planning, the pathways of primary concern would be direct deposition of radioactivity on food and water or direct release to water. The logistics of monitoring all water and foodstuffs produced within the 50 mile radius ingestion pathway emergency planning zone (EPZ) determine the resource requirements for personnel, sampling equipment, and instrumentation. Food monitoring can be done at the following locations: (1) the production level, i.e., the farm; (2) the transportation or storage level; (3) the processing level; and (4) the marketplace. If dairy farming is performed in the area and monitoring of the milk pathway is in accordance with the Phase 2 document,[a] then the monitoring of non-dairy food does not have as great an urgency since ground vegetation, soil, and surface water are usually collected at the dairy location at the time of milk sampling. A good estimate of radioiodine and other radionuclide deposition can be made based on the analyses of these environmental media. However, detailed monitoring must be conducted in the non-dairy food pathways within the ingestion EPZ at the earliest possible time.

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a Federal Emergency Management Agency, Guidance on Offsite Emergency Radiation Measurement Systems, Phase 2 - The Milk Pathway, FEMA REP-12 (September 1987).

Monitoring to determine dose commitment from food should be performed within 36 to 48 hours after passage of the airborne plume. If mature, leafy, perishable crops such as lettuce or spinach are ready for harvest, monitoring of these crops should begin as soon as a sampling plan can be formulated and sufficient resources mobilized. Food should be monitored as close to the production level as possible.

Contamination of potable water supplies via the airborne plume is not likely to be significant, but if it occurs, it probably will involve deposition of radionuclides directly on surface water supplies. Monitoring requirements for water would depend on the composition of the release and the number and type of water supplies affected. Options for monitoring locations include: (1) the initial source of deposition (stream, lake or reservoir); (2) the water supply treatment facility; or (3) output from the water treatment facility (the consumer tap). Due to the contaminating mechanisms involved, ground water monitoring would not require an immediate emergency monitoring response.

Emergency monitoring of surface deposited radioactivity should first be directed toward defining the boundaries of significantly contaminated areas, i.e., areas where the gross field measurements exceed the preventive PAG derived response levels for the most restrictive radionuclides, and later be directed toward identifying the radionuclides and quantifying levels of contamination. After the contamination boundaries have been defined, consumption of significantly contaminated foodstuffs should be limited or precautionary measures such as thoroughly washing the foodstuffs should be implemented until further radiological analyses can be conducted. Final disposition of these foodstuffs should be based on these analyses. Instruments capable of gross radiation measurement are adequate for defining the contaminated area boundaries. However, more sensitive and sophisticated instrumentation, such as NaI(Tl) detectors and single or multichannel analyzers, would be required to identify and quantify the contamination levels of specific radionuclides. Samples of contaminated foodstuffs and surface water should be collected and analyzed under controlled laboratory conditions.

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1.0 PURPOSE OF THE REPORT

In the event of a significant release of radioactive material to the environment from a nuclear power reactor facility, State and local government agencies must be prepared to protect public health and safety. There are two predominant exposure pathways by which the public can receive radiation dose following environmental releases of radioactivity. Dose can be received by plume exposure or by ingestion. Plume exposure has been defined[1] as principally constituting whole body exposure to gamma radiation from the plume or deposited material and inhalation exposure from the passing plume. Plume exposure verification is discussed in the Federal Emergency Management Agency (FEMA) document, "Guidance on Offsite Radiation Measurement Systems, Phase I - Airborne Release."[2] Ingestion exposure has been defined as internal exposure resulting from ingestion of contaminated water or food.[1] Guidance has also been provided for the milk pathway and dairy foods in the FEMA document, "Guidance on Offsite Radiation Measurement Systems, Phase 2 - The Milk Pathway".[3]

This document was developed by the Federal Radiological Preparedness Coordinating Committee (FRPCC) Subcommittee on Offsite Emergency Instrumentation for Nuclear Incidents. It provides recommendations to concerned agencies of the State, local, and Federal governments on adequate methods for planning the emergency response necessary for proper monitoring of radionuclides in non-dairy food and potable water.

The guidance provided in this document is intended to assist these agencies in determining how best to accomplish the goals of the Federally recommended Protective Action Guides (PAGs). The two levels of response are the preventive PAG and the emergency PAG. The preventive PAG establishes a projected dose commitment level at or above which responsible officials should take protective action to prevent or reduce the concentration of radioactivity in food or animal feed. Whereas, an emergency PAG establishes a projected dose commitment level at or above which responsible officials should isolate food containing radioactivity

to prevent its introduction into commerce, and at which the responsible officials must determine whether condemnation or another disposition is appropriate.

Emergency monitoring, as used in this document, refers to measuring fresh fission products in the mature food crops contaminated by an offsite release of radioactive materials, the extent and amount of deposition of these materials, and the possible ingestion of these materials by the public (or harvest of food crops for later ingestion) within 30 days of the release. Emergency monitoring for these conditions is then directed toward rapid assessment of the significantly contaminated areas, i.e., those areas where the gross field measurements indicate that the derived response levels (concentrations) may exceed the preventive PAGs, where such non-dairy food and water may exist.

In particular, recommendations made in this document concern:

1) minimum instrument requirements,
2) selection of monitoring procedures,
3) logistics and deployment of monitoring resources,
4) determination of monitoring control points, and
5) protective actions to be taken.

State and local agencies may choose to use instrument systems or monitoring procedures other than those recommended in this report. However, alternative methodologies should be reviewed and tested to assure their suitability and reliability under emergency operating conditions.

In addition to the guidance in this document and the Phase 1[2] and Phase 2[3] documents, subjects of other guidance to be developed in this series include measurements for recovery operations during the restorative phase following the radiological accident.

2.0 DESCRIPTION OF THE PROBLEM

The U. S. Nuclear Regulatory Commission (NRC) requires emergency response plans for all nuclear power plants.[4] These plans are to be coordinated with State and local government agencies. It has also been recommended[5,6] that State and local agencies formalize their emergency plans. Part of the extensive guidance available to concerned agencies is a joint NRC/Environmental Protection Agency (EPA) Task Force on Emergency Planning publication entitled "Planning Basis for the Development of State and Local Government Plans" (NUREG-0396).[1] This publication makes use of the concept of emergency planning zones (EPZs) to protect the public in the event of an accident. The same concept is required by regulation in Title 10 of the Code of Federal Regulations, Part 50 (10 CFR 50). A subsequent report, prepared by the NRC and the Federal Emergency Management Agency (FEMA), provides guidance and criteria for development of radiological emergency plans.[6]

As per 10 CFR 50.33, two EPZs are required around every nuclear power plant site: a plume exposure pathway EPZ with a radius of approximately 10 miles; and an ingestion pathway EPZ with a radius of approximately 50 miles around the plant site.[a] Initial emergency response may involve only a portion of the EPZ. Additionally, the EPZs can be circular or irregular in shape, depending on such local conditions as topography and demography (i.e., valley conditions which may restrict plume dispersion or highly populated areas located on the circumference of the EPZ, which should be totally included within or excluded from the EPZ, may dictate use of an irregularly-shaped EPZ). However, as a basis for emergency

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[a] The radius for the EPZ is source term dependent (i.e., applicable to the amount of activity and chemical forms of the radionuclides released from the nuclear power plant). The source term, in turn, depends on the power level of the nuclear plant: for example, for gas-cooled reactors and for reactors with an authorized power level less than 250 MW thermal, the EPZs may be smaller in radius; these EPZs are determined on a case by case basis.

planning, provisions should be made for analyzing representative samples of all food produced on farms or drinking water supplies within the ingestion pathway EPZ, as a confirmatory measure, to assure that radioactivity has not contaminated food or water, regardless of the eventual location of consumption.

Prior to any accidental release, the official responsible for emergency planning must establish plans for monitoring food and water. These plans should include access to a list of locations within the ingestion pathway EPZ of food production areas and water supplies, establish logistics and personnel requirements for monitoring food and water in affected areas of the EPZ during accidents of varying severity, and provide the capability to intervene in the pathways that could allow significantly contaminated food and water to reach the public.

2.1 Protective Action Levels for Non-Dairy Food and Water

Protective Action Guides (PAGs) are levels of projected dose warranting protective action. These projected doses are doses calculated assuming no protective actions were taken. For instance, this document considers the PAGs to restrict ingestion of radionuclides through the non-dairy food and water pathways. Also, these PAGs, as used by the Food and Drug Administration (FDA), are of two categories: 1) Preventive PAGs, which apply to situations where protective actions causing minimal impact on the food supply are appropriate; and 2) Emergency PAGs, which apply to incidents where protective actions of great impact on the food supply are justified because of the projected health hazard. For planning purposes, it is recommended that the planner make provisions for implementing protective actions at the preventive PAG. This enables one emergency monitoring program to accommodate the appropriate responses for both the preventive and emergency PAGs.

Responsibility for establishing standards for radionuclide concentrations in foodstuffs and water lies with two Federal agencies: The EPA for

drinking water, and the FDA for food and animal feed. FDA guidance levels on preventive and emergency PAGs are used in this document.

Dose guidelines for ingestion of contaminated food have been established by the FDA, although derived response levels for radionuclide concentration in food other than milk have yet to be issued.[7,8] Therefore, this document uses guidelines for radionuclides in non-dairy foods and water as inferred from comparing their consumption rates relative to those of milk. The preventive PAGs are 0.5 rem for whole body, bone marrow and other body organs, and 1.5 rem for the thyroid; the emergency PAGs are 5 rem for the whole body, bone marrow, and other body organs, and 15 rem for the thyroid (Table 1).[8] These PAGs include substantial safety margins; doses 20 times higher would produce no discernible health effects although the theoretical risk of cancer would be increased as much as 10 percent.

To evaluate the hazard from each nuclide in the drinking water pathway, the ingestion dose and corresponding nuclide concentrations were calculated for the organ of major concern, as delineated by the four age groups. These groups are the infant, child, teenager, and adult populations. The derived response levels (concentrations) that result in a 50 year projected dose commitment equivalent to the preventive PAGs for water are presented in Table 2. These response levels were derived based on data taken from the U. S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109.[9] The PAGs for I-131, Cs-137, Cs-134, Sr-89, and Sr-90 in milk are based on dose conversion factors for thyroid, whole body, and bone marrow. The dose conversion factors for the adult and infant age groups, for these five critical nuclides, were taken from the FDA document.[8] Dose conversion factors for all other nuclides and other age groups were taken from NRC Regulatory Guide 1.109. Drinking water ingestion rates in NRC Regulatory Guide 1.109 for the maximum exposed individual are 2 liters per day for the adult, 1.4 liters per day for the teenager and child, and 0.9 liters per day for the infant. For the purpose of this document, i.e., the early emergency phase of an accident, the ingestion period for water is assumed to be 5 days or less depending on the radionuclide mean lifetime (see Appendix A). For longer ingestion times,

TABLE 1

FDA Protective Action Guides
for Ingestion of Contaminated Foodstuffs

PAG	Organ of Interest	Dose Limit in Rem
Preventive	Whole body, bone marrow, and other organs	0.5
	Thyroid	1.5
Emergency	Whole body, bone marrow, and other organs	5
	Thyroid	15

TABLE 2

Early Emergency Phase
Derived Preventive Response Levels for Drinking Water
(Five Day Ingestion Period)[a]

Nuclide	Organ[c]	Initial Water Concentration Equivalent to the Preventive PAG Ingestion Dose Commitment[b]			
		Adult[d] (μCi/liter)	Teenager[d] (μCi/liter)	Child[d] (μCi/liter)	Infant[d] (μCi/liter)
I-131	Th	1.2E-1[e]	1.1E-1	4.5E-2	2.5E-2
I-132	Th	1.2E+1	1.4E+1	4.9E+0	3.5E-1
I-133	Th	2.4E+0	2.6E+0	9.1E-1	5.8E-1
Rb-86	Lv	2.6E+0	5.6E+0	1.9E+0	7.1E-1
Cs-134	Lv	7.4E-1	3.6E-1	1.9E-1	9.4E-1
Cs-136	Lv	2.2E+0	2.4E+0	1.3E+0	9.3E-1
Cs-137	Lv	8.2E-1	4.8E-1	2.2E-1	1.6E+0
Te-127m	Kd	1.8E+0	1.9E+0	8.8E-1	7.8E-1
Te-131m	GI	2.4E+0	3.1E+0	2.9E+0	4.4E+0
Te-132	GI	1.0E+0	1.6E+0	2.5E+0	2.7E+0
Sb-127[f]	GI	1.1E+0	1.7E+0	2.6E+0	4.8E+0
Sr-89	Bo	4.3E+0	1.7E-1	5.6E-2	5.9E-1
Sr-90	Bo	7.1E-2	8.6E-3	4.2E-3	4.5E-2
Ba-140	GI	1.4E+0	1.9E+0	9.8E-1	7.4E-1
Mo-99	Kd	9.1E+0	9.4E+0	4.6E+0	5.9E+0
Ru-103	GI	2.4E+0	3.5E+0	3.9E+0	6.4E+0
Ru-106	GI	2.8E-1	3.8E-1	3.9E-1	6.1E-1
Rh-105[f]	GI	1.2E+1	1.8E+1	2.9E+1	5.4E+1
Co-58	GI	3.4E+0	5.5E+0	7.0E+0	1.3E+1
Co-60	GI	1.2E+0	2.0E+0	2.4E+0	4.3E+0
Y-90	GI	4.9E-1	6.3E-1	6.1E-1	9.3E-1
Y-91	GI	6.6E-1	8.9E-1	9.2E-1	1.4E+0
Zr-95	GI	1.7E+0	2.4E+0	2.8+0	4.6E+0
Zr-97	GI	3.4E+0	4.0E+0	3.3E+0	4.9E+0
Nb-95	GI	2.5E+0	3.8E+0	4.6E+0	8.0E+0
La-140	GI	6.1E-1	8.3E-1	8.2E-1	1.3E+0
Ce-141	GI	2.2E+0	3.0E+0	3.0E+0	4.7E+0
Ce-143	GI	4.0E+0	5.1E+0	4.7E+0	7.1E+0
Ce-144	GI	3.0E-1	4.1E-1	4.2E-1	6.5E-1
Pr-143	GI	1.4E+0	1.9E+0	1.9E+0	2.9E+0
Nd-147	GI	1.7E+0	2.2E+0	2.3E+0	3.6E+0
Np-239	GI	4.5E+0	5.8E+0	5.5E+0	8.4E+0
Pu-238[f]	Bo	7.5E-3	9.9E-3	4.8E-3	6.9E-3
Pu-239[f]	Bo	6.4E-3	8.4E-3	3.4E-3	5.8E-3
Pu-240[f]	Bo	6.4E-3	8.4E-3	3.4E-3	5.8E-3
Pu-241[f]	Bo	3.1E-1	4.0E-1	2.0E-1	2.8E-1
Am-241[f]	Bo	1.2E-3	2.0E-2	7.8E-4	1.1E-3
Cm-242[f]	Bo	5.9E-2	7.8E-2	3.8E-2	5.3E-2
Cm-244[f]	Bo	2.5E-3	3.2E-3	1.6E-3	2.3E-3

TABLE 2 (cont'd)

Nuclide	Organ[c]	Initial Water Concentration Equivalent to the Preventive PAG Ingestion Dose Commitment[b]			
		Adult[d] (μCi/liter)	Teenager[d] (μCi/liter)	Child[d] (μCi/liter)	Infant[d] (μCi/liter)

a Assumes a contaminated water ingestion period equivalent to the shorter time interval of the radionuclide mean lifetime or 5 days (see Appendix A). Water is ingested at the rates given in Reference 9 for the maximum exposed individual.

b The derived response level for each radionuclide is capable of producing the preventive PAG dose. Therefore, if more than one radionuclide is present in the sample, the sum of ratios technique must be used to estimate the individual radionuclide concentrations that are permissible, e.g.

$$\frac{\text{Conc A}}{\text{Response Level A}} + \ldots + \frac{\text{Conc X}}{\text{Response Level X}} = \leq 1.$$

c Th=thyroid, Lv=liver, Kd=kidney, Bo=bone, Wb=whole body, GI=gastrointestinal tract. These are the critical organs for the corresponding radionuclides.

d Calculated concentrations may vary if calculation assumptions concerning ingestion rates and dose conversion factors are different from those presented in Reference 9.

e $1.2E\text{-}1 = 1.2 \times 10^{-1} = 0.12$.

f Adult dose conversion factors (DCF's) were obtained from ICRP-30;[10,11,12] dose conversion factors for other age groups were estimated by multiplying these adult DCF's by DCF ratios $\left(\frac{\text{other age group}}{\text{adult}}\right)$ presented in Reference 9 for other nuclides having similar critical organs and retention times.

to evaluate long-term usability, the derived response levels will be much lower than the concentrations presented in Table 2. The derived response levels, which are equivalent to the preventive PAG for a one year ingestion period following a water contaminating event, are presented in Table 3.

For a mixed population group, the protective actions for drinking water should be based on the derived preventive response levels for infants (see Tables 2 and 3). Also, when several radionuclides are present in water or foodstuffs, it is assumed that the sum of the multiple radionuclide ratios in all pathways should not be greater than unity. For example:

$$\frac{\text{Conc. A}}{\text{Response Level A}} + \frac{\text{Conc. B}}{\text{Response Level B}} + \frac{\text{Conc. C}}{\text{Response Level C}} = \leq 1$$

Preventive and emergency response levels for fruits, vegetables, and grains are based on daily ingestion rates (from NRC Regulatory Guide 1.109 for the maximum exposed individual) of 1.4 kg/day for an adult or child and 1.7 kg/day for the teenager. Since ingestion rates for the infant are not given, it is assumed that the average portion of fresh fruits, vegetables and grains ingested by the infant are insignificant. Daily ingestion rates for leafy vegetables are 0.18 kg/day for adults, 0.12 kg/day for teenagers, and 0.07 kg/day for children. Based on these ingestion rates, response levels resulting in a dose commitment equivalent to the preventive PAGs were derived for vegetation contamination (Tables 4 and 5). The assumptions used in these calculations are presented in Appendix A.

The meat pathway is dependent on the vegetation and water pathways and is therefore not considered for monitoring during the early emergency phase of an accident. Certain radionuclides, such as cesium, are transferred readily through the meat pathway and may contribute doses equal to the milk pathway. However, it does take some time for these radionuclides to reach their maximum concentration in the animal's body. Therefore, monitoring the meat pathway is not required during the early emergency phase

TABLE 3

Long-Term Derived Preventive Response Levels for Drinking Water[a]
(One Year Ingestion Period)

		Initial Water Concentration Equivalent to the Preventive PAG Ingestion Dose Commitment[b]			
Nuclide	Organ[c]	Adult[d] (μCi/liter)	Teenager[d] (μCi/liter)	Child[d] (μCi/liter)	Infant[d] (μCi/liter)
I-131	Th	6.3E-2[e]	5.7E-2	2.4E-2	1.3E-2
I-132	Th	1.2E+1	1.4E+1	4.9E+0	3.5E-1
I-133	Th	2.4E+0	2.6E+0	9.1E-1	5.8E-1
Rb-86	Lv	6.4E-1	1.4E+0	4.7E-1	1.8E-1
Cs-134	Lv	1.2E-2	5.8E-3	3.0E-3	1.5E-2
Cs-136	Lv	7.6E-1	8.2E-1	4.3E-1	3.2E-1
Cs-137	Lv	1.1E-2	6.6E-3	3.0E-3	2.2E-2
Te-127m	Kd	8.5E-2	8.5E-2	4.0E-2	3.6E-2
Te-129	Kd	4.0E+4	3.1E+4	9.1E+2	5.2E+2
Te-131m	GI	2.4E+0	3.1E+0	2.9E+0	4.4E+0
Te-132	GI	1.0E+0	1.6E+0	2.5E+0	2.7E+0
Sb-127[f]	GI	9.8E-1	1.5E+0	2.4E+0	4.4E+0
Sr-89	Bo	4.1E-1	1.6E-2	5.3E-3	5.6E-2
Sr-90	Bo	9.9E-4	1.2E-4	5.8E-5	6.2E-4
Ba-140	GI	4.7E-1	6.5E-1	3.4E-1	2.6E-1
Mo-99	Kd	9.1E+0	9.4E+0	4.6E+0	5.9E+0
Ru-103	GI	3.0E-1	4.3E-1	4.9E-1	7.9E-1
Ru-106	GI	5.1E-3	6.9E-3	7.2E-3	1.1E-2
Rh-105[f]	GI	1.2E+1	1.8E+1	2.9E+1	5.4E+1
Co-58	GI	2.4E-1	3.8E-1	4.9E-1	8.8E-1
Co-60	GI	1.8E-2	2.8E-2	3.6E-2	6.3E-2
Y-90	GI	6.8E-3	8.8E-3	8.5E-3	1.3E-2
Y-91	GI	5.5E-2	7.5E-2	7.7E-2	1.2E-1
Zr-95	GI	1.3E-1	1.9E-1	2.1E-1	3.5E-1
Zr-97	GI	3.4E+0	4.0E+0	3.3E+0	4.9E+0
La-140	GI	2.1E-1	2.9E-1	2.9E-1	4.5E-1
Ce-141	GI	3.2E-1	4.4E-1	4.5E-1	7.0E-1
Ce-143	GI	4.0E+0	5.1E+0	4.7E+0	7.1E+0
Ce-144	GI	5.9E-3	7.9E-3	8.2E-3	1.3E-2
Pr-143	GI	4.6E-1	6.1E-1	6.2E-1	9.6E-1
Nd-147	GI	6.5E-1	8.9E-1	9.1E-1	1.4E+0
Np-239	GI	4.5E+0	5.8E+0	5.5E+0	8.4E+0
Pu-238[f]	Bo	1.0E-4	1.4E-4	6.5E-5	9.6E-5
Pu-239[f]	Bo	8.8E-5	1.2E-4	5.4E-5	8.0E-5
Pu-240[f]	Bo	8.8E-5	1.2E-4	5.4E-5	8.0E-5
Pu-241[f]	Bo	4.4E-3	5.6E-3	2.8E-3	4.0E-3
Am-241[f]	Bo	1.7E-5	2.2E-5	1.1E-5	1.5E-5
Cm-242[f]	Bo	2.1E-3	2.7E-3	1.3E-3	1.8E-3
Cm-244[f]	Bo	3.5E-5	4.5E-5	2.2E-5	3.2E-5

TABLE 3 (cont'd)

Nuclide	Organ[c]	Initial Water Concentration Equivalent to the Preventive PAG Ingestion Dose Commitment[b]			
		Adult[d] (μCi/liter)	Teenager[d] (μCi/liter)	Child[d] (μCi/liter)	Infant[d] (μCi/liter)

a Assumes a contaminated water ingestion period equivalent to the shorter time interval of the radionuclide mean lifetime or 365 days (see Appendix A). Water is ingested at the rates given in Reference 9 for the maximum exposed individual.

b The derived response level for each radionuclide is capable of producing the preventive PAG dose. Therefore, if more than one radionuclide is present in the sample, the sum of ratios technique must be used to estimate the individual radionuclide concentrations that are permissible, e.g.

$$\frac{\text{Conc A}}{\text{Response Level A}} + \ldots + \frac{\text{Conc X}}{\text{Response Level X}} = \leq 1.$$

c Th=thyroid, Lv=liver, Kd=kidney, Bo=bone, Wb=whole body, GI=gastrointestinal tract. These are the critical organs for the corresponding radionuclides.

d Calculated concentrations may vary if calculation assumptions concerning ingestion rates and dose conversion factors are different from those presented in Reference 9.

e 6.3E-2 = 6.3×10^{-2} = 0.063.

f Adult dose conversion factors (DCF's) were obtained from ICRP-30;[10,11,12] dose conversion factors for other age groups were estimated by multiplying these adult DCF's by DCF ratios $\left(\frac{\text{other age group}}{\text{adult}}\right)$ presented in Reference 9 for other nuclides having similar critical organs and retention times.

TABLE 4

Long-Term Derived Preventive Response Levels
for Vegetable Foodstuffs[a,b]

Nuclide	Adult[c] Produce[d] µCi/kg	Adult[c] Leafy[e] µCi/kg	Teen[c] Produce µCi/kg	Teen[c] Leafy µCi/kg	Child[c] Produce µCi/kg	Child[c] Leafy µCi/kg
I-131	8.9E-2[f]	7.0E-1	4.6E-2	6.6E-1	2.3E-2	4.7E-1
I-132	1.7E+1	1.4E+2	1.1E+1	1.6E+2	4.8E+0	9.8E+1
I-133	3.4E+0	2.7E+1	2.1E+0	3.0E+1	9.0E-1	1.8E+1
Rb-86	9.1E-1	7.1E+0	1.1E+0	1.6E+1	4.6E-1	9.4E+0
Cs-134	1.7E-2	1.3E-1	4.7E-3	6.8E-2	2.9E-3	5.9E-2
Cs-136	1.1E+0	8.4E+0	6.7E-1	9.6E+0	4.3E-1	8.6E+0
Cs-137	1.6E-2	1.3E-1	5.4E-3	7.7E-2	3.0E-3	6.1E-2
Te-127m	1.2E-1	9.4E-1	6.9E-2	9.9E-1	4.0E-2	8.1E-1
Te-131	3.4E+0	2.7E+1	2.5E+0	3.6E+1	2.8E+0	5.7E+1
Te-132	1.4E+0	1.1E+1	1.3E+0	1.9E+1	2.4E+0	5.0E+1
Sb-127[g]	1.4E+0	1.1E-1	1.2E+0	1.8E+1	2.4E+0	4.8E+1
Sr-89	5.7E-1	4.5E+0	1.3E-2	1.8E-1	5.2E-3	1.1E-1
Sr-90	1.4E-3	1.1E-2	9.6E-5	1.4E-3	5.7E-5	1.2E-3
Ba-140	6.7E-1	5.3E+0	5.2E-1	7.5E+0	3.4E-1	6.8E+0
Mo-99	1.3E+1	1.0E+2	7.6E+0	1.1E+2	4.5E+0	9.1E+1
Ru-103	4.2E-1	3.3E+0	3.5E-1	5.0E+0	4.8E-1	9.7E+0
Ru-106	7.2E-3	5.7E-2	5.6E-3	8.1E-2	7.1E-3	1.4E-1
Rh-105[g]	1.7E+1	1.3E+2	1.5E+1	2.2E+2	2.9E+1	5.9E+2
Co-58	3.3E-1	2.6E+0	3.1E-1	4.4E+0	4.8E-1	9.7E+0
Co-60	2.6E-2	2.0E-1	2.3E-2	3.3E-1	3.5E-2	7.1E-1
Y-90	9.6E-3	7.5E-2	7.1E-3	1.0E-1	8.3E-3	1.7E-1
Y-91	7.8E-2	6.2E-1	6.0E-2	8.7E-1	7.6E-2	1.5E+0
Zr-95	1.8E-1	1.4E+0	1.5E-1	2.2E+0	2.1E-1	4.2E+0
Zr-97	4.8E+0	3.8E+1	3.3E+0	4.7E+1	3.3E+0	6.7E+1
Nb-95	4.9E-1	3.8E+0	4.3E-1	6.2E+0	6.3E-1	1.3E+1
La-140	3.0E-1	2.4E+0	2.3E-1	3.4E+0	2.8E-1	5.8E+0
Ce-141	4.6E-1	3.6E+0	3.6E-1	5.2E+0	4.5E-1	9.1E+0
Ce-143	5.7E+0	4.5E+1	4.1E+0	6.0E+1	4.7E+0	9.5E+1
Ce-144	8.3E-3	6.5E-2	6.4E-3	9.3E-2	8.0E-3	1.6E-1
Pr-143	6.5E-1	5.1E+0	5.0E-1	7.2E+0	6.2E-1	1.2E+1
Nd-147	9.2E-1	7.3E+0	7.2E-1	1.0E+1	9.0E-1	1.8E+1
Np-239	6.3E+0	5.0E+1	4.7E+0	6.7E+1	5.5E+0	1.1E+2
Pu-238[g]	1.4E-4	1.1E-3	1.1E-4	1.6E-3	6.4E-5	1.3E-3
Pu-239[g]	1.2E-4	9.8E-4	9.3E-5	1.3E-3	5.4E-5	1.1E-3
Pu-240[g]	1.2E-4	9.8E-4	9.3E-5	1.3E-3	5.4E-5	1.1E-3
Pu-241[g]	6.2E-3	4.8E-2	4.5E-3	6.5E-2	2.7E-3	5.6E-2
Am-241[g]	2.4E-5	1.9E-4	1.8E-5	2.6E-4	1.1E-5	2.2E-4
Cm-242[g]	2.9E-3	2.3E-2	2.2E-3	3.1E-2	1.3E-3	2.6E-2
Cm-244[g]	4.9E-5	3.9E-4	3.7E-5	5.3E-4	2.2E-5	4.4E-4

TABLE 4 (cont'd)

Nuclide	Adult[c] Produce[d] µCi/kg	Adult[c] Leafy[e] µCi/kg	Teen[c] Produce µCi/kg	Teen[c] Leafy µCi/kg	Child[c] Produce µCi/kg	Child[c] Leafy µCi/kg

a Assumes an ingestion period equivalent to the shorter time interval of the radionuclide mean lifetime or 365 days (see Appendix A). Leafy vegetables and other produce are ingested at the rates given in Reference 9 for the maximum exposed individual. Also, assumes that the produce and leafy vegetables are harvested shortly after a contaminating event.

b The derived response level for each radionuclide is capable of producing the preventive PAG dose. Therefore, if more than one radionuclide is present in the sample, the sum of ratios technique must be used to estimate the individual radionuclide concentrations that are permissible, e.g.

$$\frac{\text{Conc A}}{\text{Response Level A}} + \ldots + \frac{\text{Conc X}}{\text{Response Level X}} = \leq 1.$$

c Calculated concentrations may vary if calculation assumptions concerning ingestion rates and dose conversion factors are different from those presented in Reference 9.

d Produce = Non-leafy vegetables, fruits, and grains.

e Leafy = Leafy vegetables.

f 8.9E-2 = 8.9×10^{-2} = 0.089.

g Adult dose conversion factors (DCF's) were obtained from ICRP-30;[10,11,12] dose conversion factors for other age groups were estimated by multiplying these adult DCF's by DCF ratios $\left(\frac{\text{other age group}}{\text{adult}}\right)$ presented in Reference 9 for other nuclides having similar critical organs and retention times.

TABLE 5

Short-Term Derived Preventive Response Levels for Vegetable Foodstuffs[a,b]

Nuclide	Adult[c] Produce[d] µCi/kg	Adult[c] Leafy[e] µCi/kg	Teen[c] Produce µCi/kg	Teen[c] Leafy µCi/kg	Child[c] Produce µCi/kg	Child[c] Leafy µCi/kg
I-131	1.3E-1[f]	9.9E-1	6.4E-2	9.3E-1	3.3E-2	6.7E-1
I-132	2.0E+1	1.6E+2	1.3E+1	1.9E+2	5.6E+0	1.1E+2
I-133	3.5E+0	2.8+1	2.2E+0	3.2E+1	9.4E-1	1.9E+1
Rb-86	1.8E+0	1.4E+1	2.2E+0	3.1E+1	9.0E-1	1.8E+1
Cs-134	2.6E-1	2.1E+0	7.5E-2	1.1E+0	4.7E-2	9.5E-1
Cs-136	1.8E+0	1.4E+1	1.1E+0	1.6E+1	7.0E-1	1.4E+1
Cs-137	2.9E-1	2.3E+0	9.6E-2	1.4E+0	5.4E-2	1.1E+0
Te-127m	7.6E-1	6.0E+0	4.4E-1	6.3E+0	2.5E-1	5.1E+0
Te-131m	3.6E+0	2.9E+1	2.7E+0	3.8E+1	3.0E+0	6.1E+1
Te-132	1.7E+0	1.3E+1	1.5E+0	2.2E+1	2.9E+0	5.8E+1
Sb-127[g]	1.6E+0	1.3E+1	1.5E+0	2.1E+1	2.8E+0	5.7E+1
Sr-89	2.0E+0	1.6E+1	4.6E-2	6.6E-1	1.9E-2	3.8E-1
Sr-90	2.5E-2	2.0E-1	1.7E-3	2.5E-2	1.0E-3	2.1E-2
Ba-140	1.1E+0	8.7E+0	8.6E-1	1.2E+1	5.5E-1	1.1E+1
Mo-99	1.5E+1	1.2E+2	8.7E+0	1.3E+2	5.1E+0	1.0E+2
Ru-103	1.2E+0	9.8E+0	1.0E+0	1.5E+1	1.4E+0	2.9E+1
Ru-106	1.0E-1	8.2E-1	8.1E-2	1.2E+0	1.0E-1	2.1E+0
Rh-105[g]	1.8E+1	1.4E+2	1.6E+1	2.3E+2	3.1E+1	6.4E+2
Co-58	1.5E+0	1.2E+1	1.4E+0	2.0E+1	2.2E+0	4.4E+1
Co-60	4.4E-1	3.5E+0	4.0E-1	5.7E+0	6.0E-1	1.2E+1
Y-90	1.7E-1	1.4E+0	1.3E-1	1.8E+0	1.5E-1	3.0E+0
Y-91	3.1E-1	2.4E+0	2.4E-1	3.4E+0	3.0E-1	6.0E+0
Zr-95	7.5E-1	5.9E+0	6.3E-1	9.1E+0	8.7E-1	1.8E+1
Zr-97	5.0E+0	3.9E+1	3.4E+0	4.9E+1	3.4E+0	6.9E+1
Nb-95	1.3E+0	1.0E+1	1.2E+0	1.7E+1	1.7E+0	3.5E+1
La-140	5.0E-1	3.9E+0	3.8E-1	5.5E+0	4.7E-1	9.5E+0
Ce-141	1.2E+0	9.4E+0	9.3E-1	1.3E+1	1.2E+0	2.4E+1
Ce-143	6.1E+0	4.8E+1	4.4E+0	6.4E+1	5.0E+0	1.0E+2
Ce-144	1.1E-1	9.0E-1	8.8E-2	1.3E+0	1.1E-1	2.2E+0
Pr-143	1.1E+0	8.6E+0	8.4E-1	1.2E+1	1.0E+0	2.1E+1
Nd-147	1.4E+0	1.1E+1	1.1E+0	1.6E+1	1.4E+0	2.8E+1
Np-239	7.1E+0	5.6E+1	5.2E+0	7.6E+1	6.1E+0	1.2E+2
Pu-238[g]	2.6E-3	2.0E-2	2.0E-3	2.9E-2	1.2E-3	2.4E-2
Pu-239[g]	2.2E-3	1.8E-2	1.7E-3	2.4E-2	9.7E-4	2.0E-2
Pu-240[g]	2.2E-3	1.8E-2	1.7E-3	2.4E-2	9.7E-4	2.0E-2
Pu-241[g]	1.1E-1	8.6E-1	8.0E-2	1.2E+0	4.9E-2	9.9E-1
Am-241[g]	4.3E-4	3.4E-3	3.2E-4	4.7E-3	1.9E-4	3.9E-3
Cm-242[g]	2.3E-2	1.8E-1	1.7E-2	2.5E-1	1.0E-2	2.1E-1
Cm-244[g]	8.8E-4	6.9E-3	6.5E-4	9.4E-3	3.9E-4	7.8E-3

TABLE 5 (cont'd)

Nuclide	Adult[c] Produce[d] µCi/kg	Adult[c] Leafy[e] µCi/kg	Teen[c] Produce µCi/kg	Teen[c] Leafy µCi/kg	Child[c] Produce µCi/kg	Child[c] Leafy µCi/kg

a Assumes an ingestion period equivalent to the shorter time interval of the radionuclide mean effective lifetime (includes weathering and radioactive decay) or 30 days (see Appendix A). Leafy vegetables and other produce are ingested at the rates given in Reference 9 for the maximum exposed individual. Produce and leafy vegetables are assumed to remain in the garden or field until the time of consumption.

b The derived response level for each radionuclide is capable of producing the preventive PAG dose. Therefore, if more than one radionuclide is present in the sample, the sum of ratios technique must be used to estimate the individual radionuclide concentrations that are permissible, e.g.

$$\frac{\text{Conc A}}{\text{Response Level A}} + \ldots + \frac{\text{Conc X}}{\text{Response Level X}} = \leq 1.$$

c Calculated concentrations may vary if calculation assumptions concerning ingestion rates and dose conversion factors are different from those presented in Reference 9.

d Produce = Non-leafy vegetables, fruits, and grains.

e Leafy = Leafy vegetables.

f $1.3E\text{-}1 = 1.3 \times 10^{-1} = 0.13$.

g Adult dose conversion factors (DCF's) were obtained from ICRP-30;[10,11,12] dose conversion factors for other age groups were estimated by multiplying these adult DCF's by DCF ratios $\left(\frac{\text{other age group}}{\text{adult}}\right)$ presented in Reference 9 for other nuclides having similar critical organs and retention times.

of an accident. Monitoring the meat pathway should begin later, during the recovery and reentry phase of the accident. In an event where the drinking water or vegetable response levels are exceeded, it would be prudent to recommend delaying consumption of meat with potential for significant contamination until it can be monitored.

2.2 Determining the Nuclides of Concern

While such releases have never occurred in the United States, two "credible" modes are postulated for contamination of food and water resulting from a nuclear incident: 1) airborne release; and 2) the release of radionuclides into water. A schematic representation of the movement of radionuclides is presented in Figure 1. Both modes of radionuclide release are considered in the Reactor Safety Study (RSS)[13], although no source terms are provided for the latter.

Four potential pathways have been identified by which radionuclides released during an accident may contaminate food supplies: 1) direct deposition on edible plants; 2) deposition via contaminated irrigation water; 3) uptake by plants from soil; and 4) deposition on edible plants by resuspension of radionuclides deposited on soil. The pathways resulting in contamination of potable water supplies include: 1) airborne plume deposition on surface water; 2) runoff from soil or snow contaminated by the plume; 3) leaching and/or migration of radioactive fluids to water supplies; and 4) direct release of contaminated effluents to a river or other water body that supplies drinking or irrigation water. The only credible short-term hazard for contamination of food and water is direct deposition from the airborne plume or direct discharge of contaminated liquid effluents to a drinking water supply. Therefore, these are the pathways used to calculate dose projections in this document.

Any or all of the radionuclides in the reactor core, except the noble gases, can potentially be deposited on crops or in water supplies. The initial concentration in food and water will depend on several factors:

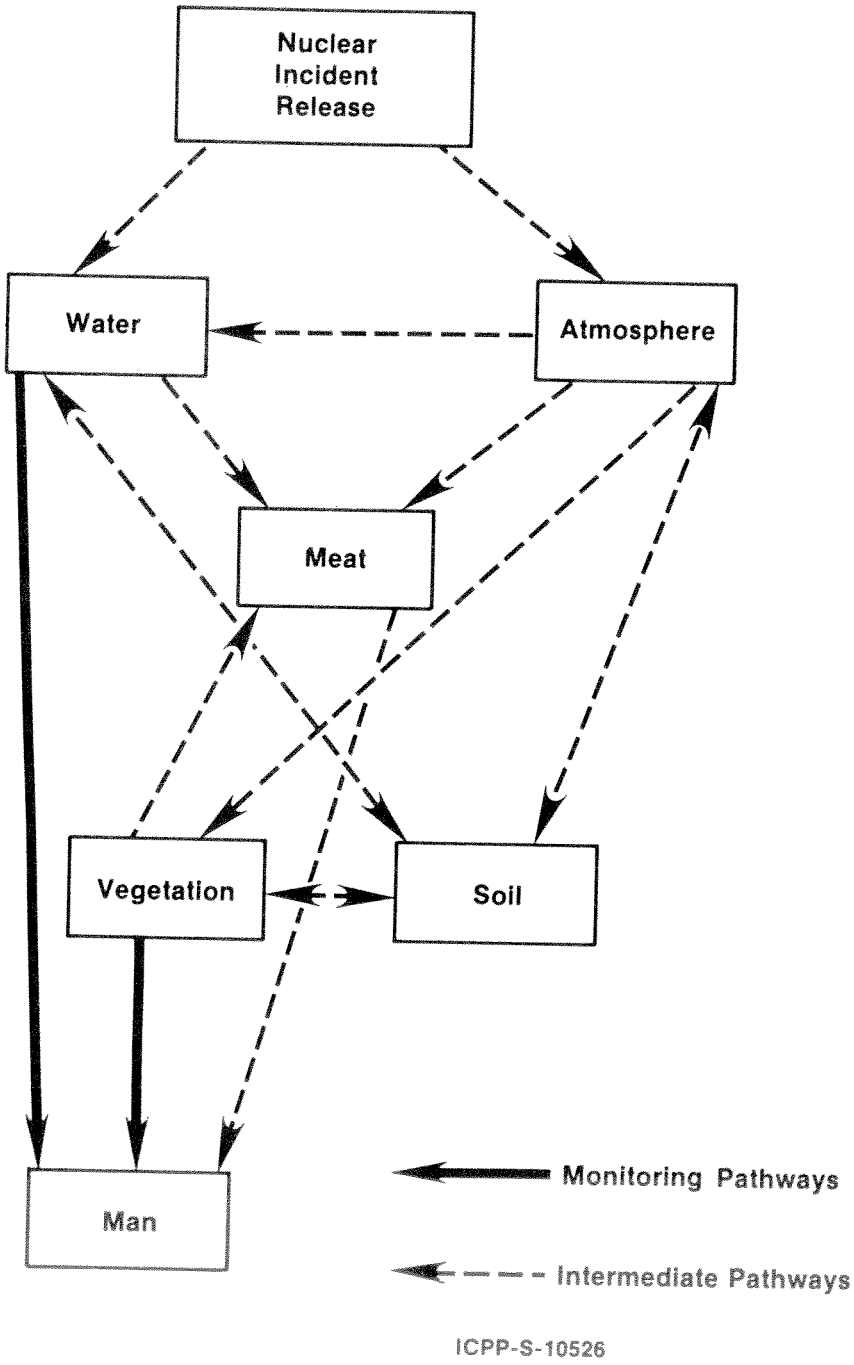

Figure 1. Radionuclide Ingestion Pathways to Man From a Nuclear Incident Release---Excluding the Milk Pathway

1) the type and the severity of the accident, i.e., the amount and number of radionuclides released; 2) the meteorological conditions during the accident; 3) the distance the field or water supply is located from the accident site; and 4) the geography and type of flora, i.e., grain fields, orchards, etc., which can significantly influence deposition and retention of radionuclides. Another important factor affecting the degree of contamination of drinking water is the source of the water supply, i.e., surface water or aquifer. Therefore, the resulting concentrations in food or water can vary from insignificant levels to levels orders of magnitude greater than the derived preventive response levels.

In order to give an estimate of the potential problem from accidents of varying severity, a review of existing literature was made and a range of radionuclide concentrations possible in food after accidents in light-water reactors was calculated. Source terms, the amounts of activity released, were taken primarily from the RSS.[13] The RSS provides estimates of the probability of specific accidents as well as the amounts of various nuclides released.[a] The RSS divides the radionuclides present in the reactor core into several categories based on estimates of their post accident behavior. Not all scenarios from the RSS were reviewed since the purpose is to give an understanding of the potential problem. Two accidents, one severe and one less severe, from the RSS are used as examples to illustrate possible accident situations: 1) an accident which releases significant amounts of activity over an extended time span which would probably require extensive monitoring of the EPZ area; 2) a more trivial accident in which the amount of activity released is small, the time span is short, and monitoring is required on only a small portion of the EPZ area. These examples are not intended as specific accidents on which to base emergency plans.

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[a] It is not within the scope of this report to discuss the probabilities of potential accidents in nuclear power plants or the associated source terms (the amount and chemical forms of the radionuclides released from the plant). However, it should be noted that a number of ongoing research studies of severe reactor accident source terms suggest the RSS over estimates the radioiodine releases by a factor of ten or more and may also over estimate the releases of a large number of other radionuclides in particulate form.

The accident scenarios in the RSS are put in sets called release categories based on the size of radioactive releases. Each release category is numbered, with group 1 having the greatest release fraction and group 9 the least. The first example accident is shown in Table 6 and is designated PWR-7 AGH-epsilon by RSS. The PWR-7 denotes a specific pressurized water reactor accident sequence with a release category of 7. AGH-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, designated BWR-5A and shown in Table 6, is a boiling water reactor accident with a release category of 5. The accident involves a rupture of the reactor coolant boundary but all engineered safety features operate as designed.

Plume concentrations were calculated from the RSS source terms using the assumptions in Regulatory Guides 1.3[14] and 1.4[15]; these estimates are considered conservative so the actual concentrations are likely to be much lower. Radionuclide surface concentrations (Table B-2) were then calculated using the methodology in USNRC Regulatory Guide 1.111[16]. To evaluate the relative consequences of ingesting radionuclides in food, these surface concentrations and the methodology in NRC Regulatory Guide 1.109 were used to determine dose commitment. The results are presented in Table B-3. The dose commitments are calculated for the critical organ (i.e., the organ where the highest doses occur for the amount of radioactivity ingested) for the most sensitive segment of the population.

The results shown in Table B-3 were divided by the preventive PAG dose level. The ratios of the predicted dose to the preventive PAG dose levels are shown in Tables 7 and 8 for the two example accident sequences. Ratios greater than one indicate projected doses in excess of the preventive PAG response level. (A complete description of the methodology used in the dose calculations is presented in Appendix B.) Since the size (i.e., surface area to volume ratios) of water storage reservoirs as well

TABLE 6

Description of Two Examples of Reactor Accident Sequences

Accident	Initiating Event	ESF Failure[a]	Containment Failure
PWR 7 AGH-epislon	A - large loss of coolant accident (LOCA)	H - emergency core cooling system (ECCS) failure G - failure of containment heat removal system	epsilon - containment base mat melt through
BRW 5A	A - rupture of reactor coolant boundary		

[a]ESF - Engineered Safety Features

TABLE 7

Projected Ratio of Foodstuff Pathway Dose to Preventive PAG for Selected Accident Sequences (PWR-7 AGH-Epsilon)[a]

Nuclide	Organ[b]	Ratio of Dose to Preventive PAG for Food Grown at 300m	1600m (1 mi)	8000m	16000m (10 mi)	32000m	8000m (50 mi)
I-131	Th	>1000	287	13	3.8	0.99	0.14
I-132	Th	c					
I-133	Th	60	4.1	0.19	0.05	0.01	0.002
I-134	Th						
I-135	Th	0.15	0.01				
Rb-86	Lv	0.001					
Cs-134	Lv	59	4.1	0.19	0.05	0.01	0.002
Cs-136	Lv	0.040	0.003				
Cs-137	Lv	31	2.1	0.10	0.03	0.007	0.001
Te-127	GI						
Te-127m	Kd	1.2	0.08	0.004	0.001		
Te-129	GI						
Te-129m	Kd						
Te-131m	GI						
Te-132	GI	0.009					
Sb-127	GI[d,e]						
Sb-129	GI[d,e]						
Sr-89	Bo	49	3.4	0.16	0.04	0.01	0.002
Sr-90	Bo	135	9.3	0.43	0.12	0.03	0.005
Sr-91	GI						
Ba-140	GI	0.34	0.02	0.001			
Mo-99	Kd						
Tc-99	GI						
Ru-103	GI	1.9	0.13	0.006	0.002		
Ru-105	GI						
Ru-106	GI	17	1.2	0.06	0.02	0.004	
Rh-105	GI						
Co-58	GI	0.02	0.001				
Co-60	GI	0.04	0.003				
Y-90	GI						
Y-91	GI	2.7	0.02	0.009	0.002		
Zr-95	GI	1.4	0.09	0.004	0.001		
Zr-97	GI						
Nb-95	GI	0.38	0.03	0.001			
La-140	GI						
Ce-141	GI	0.43	0.03	0.001			
Ce-143	GI						
Ce-144	GI	10	0.70	0.033	0.009	0.002	
Pr-143	GI	0.07	0.005				

TABLE 7 (cont'd)

Nuclide	Organ[b]	Ratio of Dose to Preventive PAG for Food Grown at 300m	1600m (1 mi)	8000m	16000m (10 mi)	32000m	8000m (50 mi)
Nd-147	GI	0.01					
Np-239	GI	c					
Pu-238	Bo[d,e]	38	2.5	0.12	0.04	0.009	0.001
Pu-239	Bo[d,e]	16	1.1	0.05	0.02	0.004	
Pu-240	Bo[d,e]	16	1.1	0.05	0.02	0.004	
Pu-241	Bo[d,e]	50	3.5	0.16	0.05	0.01	0.002
Am-241	Bo[d,e]	1.3	0.09	0.004	0.001		
Cm-242	Bo[d,e]	1.7	0.11	0.005	0.002		
Cm-244	Bo[d,e]	8.4	0.58	0.03	0.008	0.002	

a Preventive PAG for the maximum exposed individual equivalent to an organ dose of 0.5 rem for organs other than thyroid. Ratios greater than 1 indicate a projected dose in excess of PAG and therefore are of concern.

b Th=thyroid, Lv=liver, WB=whole body, Bo=bone, GI=gastro-intestinal tract Kd=kidney.

c All blank spaces in table have a ratio <0.001.

d Dose conversion factors taken from Wash-1400 Appendix VI.

e Soil transfer coefficient not available, dose due to direct deposition only.

TABLE 8

Projected Ratio of Foodstuff Pathway Dose to Preventive PAG for Selected Accident Sequences (BWR 5A)[a]

		Ratio of Dose to Preventive PAG for Food Grown at					
Nuclide	Organ[b]	300m	1600m (1 mi)	8000m	16000m (10 mi)	32000m	8000m (50 mi)
I-131	Th	0.002	c				
I-132	Th						
I-133	Th						
I-134	Th						
I-135	Th						
Rb-86	Lv						
Cs-134	Lv	0.02	0.002				
Cs-136	Lv						
Cs-137	Lv	0.01					
Te-127	GI						
Te-127m	Kd						
Te-129	GI						
Te-129m	Kd						
Te-131m	GI						
Te-132	GI						
Sb-127	GI[d,e]						
Sb-129	GI[d,e]						
Sr-89	Bo						
Sr-90	Bo						
Sr-91	GI						
Ba-140	GI						

a Preventive PAG for the maximum exposed individual equivalent to an organ dose of 0.5 rem for organs other than thyroid. Ratios greater than 1 indicate a projected dose in excess of PAG and therefore are of concern.

b Th=thyroid, Lv=liver, WB=whole body, Bo=bone, GI=gastro-intestinal tract Kd=kidney.

c All blank spaces in table have a ratio <0.001.

d Dose conversion factors taken from Wash-1400 Appendix VI.

e Soil transfer coefficient not available, dose due to direct deposition only.

as water-shed areas will vary greatly, radionuclide concentrations in water supplies were not estimated.

A third example which may only affect the water pathway is a loss of condensate water accident. Such a failure is considered improbable because these tanks are classified "safety related" and they are designed and constructed to rigid standards. Depending on the reactor type, the condensate water storage tank may contain a large quantity of tritium. These tanks are located outside the containment structure. If one of these tanks should rupture, a fairly large quantity of tritium-contaminated water could be released directly to the environment. This type of accident, however, is of limited consequence due to rapid dilution by uncontaminated water. The emergency planner should be aware of seasonal stream flow conditions so that the necessary calculations can be made to determine the scope of sampling or the type of protective actions to be taken. In any case, confirmatory field sampling should be implemented as soon as possible following the release.

The scenario postulated in the RSS for contamination of groundwater via leaching of radionuclides involves a core meltdown. The molten core penetrates the containment floor releasing radioactive fluids into the soil beneath. Another scenario (not discussed in the RSS) would be a release from a storage tank containing contaminated water. The time for radionuclides to penetrate soil depends on soil composition and varies from hours for sandy soil to years for silty clays.[17] Also, the soil is expected to retain significant quantities of radionuclides, lowering the ground water radionuclide concentration levels.

If either scenario were to occur, radionuclide concentrations would be reduced due to partial retention of solids by soil and to dilution by groundwater and other water sources prior to reaching a potable water supply. Such postulated accidents are analyzed during licensing and shown to have no serious consequences off-site. Although no source terms were postulated in the RSS for either scenario, applicable derived radionuclide

concentrations that warrant protective actions were calculated and are shown in Tables 2 and 3.

Tables 4 and 5 contain the derived radionuclide concentrations that trigger protective actions for foodstuffs. In calculating the dose commitments from deposition of the airborne plume, it was assumed that fruits, vegetables, and grains were harvested for consumption immediately after radionuclide deposition. While this situation may be applicable only to family owned vegetable gardens or commercial roadside stands where fresh fruits and vegetables are sold, it is a "conservative" assumption; that is, it tends to overestimate doses and thereby to call for protective actions that are not totally justified. In most cases ingestion immediately after deposition probably will not occur. Time delays may occur between radionuclide deposition and actual ingestion, perhaps as a result of the time between deposition and harvest or perhaps as a result of the time involved for transportation, storage or processing.

These delays decrease the intake of radioiodines because of their short half-lives (8 days or less), however, no such decrease occurs for the longer half-life radionuclides, such as cesium and strontium although they are removed from surfaces by natural forces such as wind and rain.

The time of year the accident occurs also affects the potential dose received by the public and therefore the protective action to be taken. For example, an accident that occurred outside the growing season would not require the same urgency as an accident that occurred just before harvest.

While ingestion of contaminated meat could add to the public's potential dose, emergency monitoring to determine dose commitment need not be based on the meat pathway. This pathway is dependent on the vegetation and water pathways. However, this does not mean protective actions will never be necessary to reduce potential doses from the meat pathway (e.g., removing livestock from contaminated feed).

Accurate predictions of the total radioactivity in a mixed diet (in the event of a nuclear incident) are difficult. The predictions are complicated because only a limited area would be affected and some or all food consumed by an individual could be produced in areas not affected by the release, or produced before the release.[18]

2.2.1 Radioiodines. The RSS divides the reactor core inventory into several categories based on the post accident behavior or the various nuclides. One category is the radiohalogens, consisting of the radiobromines and radioiodines. The radiobromines would not present a potential dose problem due to their short half-lives. The fission produced radioiodines consist of six nuclides; I-129, I-131, I-133, I-134, and I-135. The core inventory of I-129 will not be in equilibrium because of the long half-life of this nuclide; the remaining radioiodine isotopes may be in equilibrium in most reactor cores. The long half-life of the I-129 results in a much reduced inventory in terms of curies when compared to the remaining five iodine isotopes. Therefore, the consequences of an accidental release of the radiohalogens is governed by the five radioiodine isotopes with mass 131 through 135.

The pathways by which radioiodine could contaminate food and water have already been presented. The thyroid would receive the majority of the dose from radioiodine ingested with contaminated food and is therefore considered the critical organ. The thyroid dose from radioiodine via ingestion would be higher for children than adults (according to our models) because of the smaller thyroid mass and higher thyroid uptake. Therefore, the child (older than one year) is considered the critical segment of the population.[9] In a few cases the teenager is the critical segment of the population. Although the infant is the critical segment of the population for the milk[3] and water pathways, the infant is not the critical segment of the population for food because it is assumed the infant ingests an insignificant portion of fresh fruits, grains, and vegetables.

2.2.2 Other Radionuclides. The ingestion pathways for radioiodine are applicable to the particulates and heavy metals. Any or all of the radionuclides in Tables 7 and 8 may be present in food or water depending on the accident scenario. However, the hazard immediately after an accident will be greater for radioiodine than for strontium, cesium, and heavy metals under most reactor accident scenarios. These radionuclides will be released as particulates in smaller fractions than radioiodine, which will be in both the particulate and the gaseous phases. In addition, the assumed deposition velocity is greater for gaseous elemental iodine (0.01 m/sec) than for particulates (0.001 m/sec).[19] These factors result in more radioiodine than other radionuclides deposited on vegetation. The result is a higher concentration of radioiodine on foods which may be consumed by members of the public.

The assumed uptake fractions of other radionuclides to respective critical organs (bone marrow for Sr and the whole body or liver for Cs) is considerably less than the uptake of I-131 by the thyroid.[20] When all these factors are considered, radioiodine dominates the ingestion dose, as shown in Tables 7 and 8. For even more unlikely scenarios where Sr, Cs, or other long-lived radionuclides might rival the I-131 release to the environment, preventive response levels for these long-lived radionuclides may be expected to appear at greater distances from the plant site (i.e., possibly beyond the 10 mile plume exposure EPZ).

The particulates are expected to remain on vegetation longer because of their (assumed) longer effective half-lives (11-14 days) compared to that of radioiodine (5 days)[21]; this creates the potential for exposure over a longer period of time (see Table A-2). However, as illustrated in Table B-2, radioiodine concentrations on forage (calculated from RSS source terms) will be greater than that of all other radionuclides, in spite of the slightly longer effective half-lives of other radionuclides. Therefore, protective action taken for radioiodine will eliminate any short term problems from deposition of other radionuclides.

Accident scenarios can be postulated where other radionuclides, especially Cs-137 and Sr-90, rather than radioiodine, would be the radionuclides of concern. These postulated accidents are of minor consequence. An example of such a scenario could be a fuel pool accident where the radioiodine in the fuel has decayed to insignificant levels.

2.2.3 Summary. A review of Tables 7 and 8 indicates that the radioiodines, in particular I-131, initially dominate the dose via the ingestion pathway for these two RSS accident scenarios. For emergency planning the pathway of primary concern is direct deposition on food and water or direct release to water. Scenarios may be postulated where the time delay between start of the accident and release to the environment is long enough to allow radioiodine to decay to insignificant levels. In these scenarios, cesium and strontium are the radionuclides of major concern.

3.0 MONITORING REQUIREMENTS AND DOSE REDUCTION ACTIONS

The resources required to monitor for potentially contaminated food crops and water supplies will be site specific. The emergency planner must evaluate all monitoring resources before selecting the most appropriate monitoring system.

Important considerations for the emergency planner are: 1) monitoring and/or sampling locations; 2) personnel requirements; 3) sampling and/or monitoring procedures; and 4) instrument requirements. These are discussed below.

3.1 Monitoring the Non-Dairy Food Pathway

Monitoring requirements for the non-dairy food pathway will depend on the composition of the release, the time of year, and the number and type of farms in the ingestion pathway EPZ. Options for monitoring locations include: 1) the production level (i.e., the farm), 2) the transportation and/or storage level; 3) the processing level; and 4) the marketplace. The urgency for monitoring other foods when milk is also a consideration is not great, since a good estimate of radioiodine and other radionuclide deposition can be made based on the analyses of ground vegetation, soil and surface water samples which are usually collected at the dairy location at the time of milk sampling. However, detailed monitoring must be conducted in the non-dairy food pathways within the ingestion EPZ at the earliest possible time. (The milk monitoring system has been described in a previous document.[3])

The monitoring requirements for the food pathway will depend on the accident. The accidents with the highest probability of occurring, result in releases of the least quantities of radioactive material. The composition of the release will affect the number of sample measurements required and the overall duration of the monitoring program. For example, if facility

data and field measurements of the airborne plume indicate that the radioactive release consists of only noble gases, then any foodstuff contaminated in the downwind areas should only consist of the short-lived, particulate, noble gas daughter products. (Where daughters are not short-lived, relatively little of the daughters will be produced. For example, it takes 86 curies of Xe-125 to produce a single curie of I-125.) These short-lived daughter products will decay to insignificant levels within 5 to 6 hours following deposition. In this case, measurements of surface vegetation foodstuff samples collected from an area coinciding with the highest airborne plume measurement (e.g., plume centerline measurements) will suffice for confirmatory analysis to determine that other long-lived nuclides are not present in significant quantities. However, if the release contains radioiodine or radioiodine and particulate radionuclides along with the noble gases, a more extensive sampling and monitoring program will be required (see Section 4.2.1 for details of these procedures) to determine whether contamination levels, if ingested, will exceed the projected PAG dose limits. If only radioiodine and noble gases are present in the release, an additional followup monitoring program may be warranted to determine when these short-lived radionuclides have decayed to concentration levels which may be safe for human consumption.

Following a release of radioactive material and its subsequent deposition on vegetable foodstuffs, all potentially significantly contaminated foodstuffs should be controlled[a] or precautionary protective actions, such as thorough washing, implemented until the emergency preparedness decisionmakers can make an informed decision, based upon laboratory analyses, regarding the ultimate disposition (e.g., release for consumption or condemnation) of these foodstuffs. The time of year will influence the time frame within which the decisionmakers must respond. For example, if the radioactive deposition were to occur just prior to, or during the

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a If possible, it is important to delay consumption until the degree of contamination is known.

harvest season for perishable food crops, a rapid, informed decision must be made in order to avoid the economic impacts which may result from the spoiling of uncontaminated foodstuffs. Thus the time of year may ultimately determine the number of monitoring team personnel that must be mobilized. For rapid field monitoring of contaminated foodstuffs, gross field measurements at a given time and location should be coupled with sample collection and laboratory analysis (e.g., gamma spectroscopy and/or chemical separation) for specific nuclide determination. These laboratory analyses may then be used in conjunction with the gross field measurements to estimate the radionuclide concentrations which may be used as a basis for determining the disposition of the contaminated foodstuffs.

The number and type of farms in the ingestion pathway EPZ will impact the number of samples to be collected and ultimately the number of sampling/monitoring personnel which will have to be mobilized. In the affected area, i.e., area where field measurements indicate detectable levels of contamination, samples of each produce type and associated gross survey measurements from each sampling location will be required before foodstuffs can be released for consumption. Sampling and monitoring priorities may be assigned within the affected area, e.g., above ground crops would have priority over root crops and within the above ground crop groups, those that are most perishable should be sampled and monitored first.

In addition to the release composition, the effect of release duration should also be considered when determining the monitoring requirements for the non-dairy food pathway. If the release duration is short (e.g., minutes to an hour), only a small portion, one to four sectors depending on local meteorological conditions, of the ingestion pathway EPZ may potentially be contaminated by deposition from the airborne plume. However, a long-term release, e.g., hours to days, has a greater probability that windshifts may occur and thus a greater probability that larger portions of the ingestion pathway EPZ may potentially be contaminated. The behavior of low-level winds is uncertain and it would be a mistake

to assume that wind direction will not change in a few minutes or that it will be the same a few meters away.

The effect of rainfall should also be considered when determining potentially contaminated areas. Rainfall can act as a scavenger of airborne radionuclides, resulting in areas of greater deposition. It is possible that even though an airborne plume does not deposit significant radioactivity at locations near the accident site, if a rain occurs, the plume may deposit higher concentrations at more distant locations. In turn, the rain may also wash off contamination.

Early indication of potentially contaminated areas and their levels of deposited activity may be obtained by predictive information from the nuclear plant dose projection system, Atmospheric Release Advisory Capability (ARAC) projections, the plume exposure rate verification system, the milk monitoring system, and the Aerial Measuring System (AMS) (see Appendix C and Section 4.1 of this document for further discussion of AMS and its detections sensitivity). Emphasis should be placed on measurements because the best of projections are subject to great uncertainty.

Monitoring to determine the dose commitment from food should be performed within 36 to 48 hours after the passage of the airborne plume. If mature leafy perishable crops, e.g., lettuce, spinach, etc., are affected, monitoring of these crops should begin as soon as a sampling plan can be formulated and sufficient resources mobilized. Information from the capabilities listed above should be available within a 36 to 48 hour time period. In addition, a public notification procedure could be used to inform the family farmer not to consume foodstuffs, without thoroughly washing first, from the affected area until monitoring can be accomplished.

The extent of the sampling grid will depend on the extent of the area affected by the plume as determined from the above mentioned capabilities and by ground level radiological surveys (specific details on sampling and monitoring procedures are discussed in Section 4.2.1 of this document). The emergency planner, when determining the proper monitoring location,

should consider the different types of food producing entities that may be present in the EPZ. These include: 1) commercial farms that produce food for public market; 2) small family farms that may produce some food for commercial market, may sell crops at a roadside stand or consume a portion of the food produced; and 3) the family garden where all food produced is consumed at that location. Food must be monitored at the production level in order to ensure that crops produced and consumed at the same location will be monitored.

The time of year an accident occurs is an important consideration in planning for crop monitoring. Monitoring should be planned for the "worst case", harvest time, by the emergency planner. Release and deposition during the growing season could also result in unnecessary exposure to the public; however, it will not require the immediate response necessary during harvest. Deposition on soil could also result in dose to the public. The longer half-life radionuclides (cesium and strontium) will remain in the soil and may be taken up by plants during the growing season and in future growing seasons.[18] Evaluation of the uptake of these radionuclides is part of the recovery effort and will be covered in a future document.

3.2 Monitoring the Water Pathway

As discussed in Section 2, potable water supplies may be contaminated by direct deposition, washout or rainout from the airborne plume, runoff from areas contaminated by direct deposition from the airborne plume, leaching of radioactive fluids into groundwater or surface water supplies, or direct release of contaminated liquid effluents into the water supply.[a]

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a The subcommittee on offsite emergency instrumentation does not consider significant contamination of surface water by direct deposition of airborne radioactivity to be a highly probable occurrence. Although monitoring this mode of water contamination is briefly discussed, the major emphasis of this document is directed toward monitoring a more credible water contaminating event which is the direct release of contaminated liquids into a drinking water supply such as a river or stream.

Sampling or monitoring at the water treatment facility will allow determination of the radionuclide concentration of all water entering the public water supply. Appropriate protective action (control of contaminated water, chemical treatment, etc.) can be taken when concentrations exceed the preventive response level. Technical personnel who routinely perform water analyses at water treatment facilities should be trained to monitor water for radioactive contamination in emergency situations. Their training should include: 1) proper operation of hand-held radiation detectors, such as a 1.25"x1.5" or 2"x2" NaI(Tl) detector and a count ratemeter; 2) procedures for sampling and monitoring water with either the immersion method or the ion exchange method, as recommended for emergency milk monitoring[3]; and 3) procedures for collection and preservation of water samples for subsequent confirming analyses at a radioanalytical laboratory (Section 4.2.3).

Water can be sampled or monitored after passing through the water treatment facility, e.g., either drinking water or irrigation water. Monitoring after passage through the treatment facility should be used to confirm that the appropriate protective action has been taken and that unacceptable levels of radioactivity are not reaching the public.

The emergency planner should consider water utility personnel in the plan and obtain their cooperation for monitoring of radioactivity and taking protective action. An open exchange of information will be necessary between the Emergency Operations Center (EOC) and the water utility to activate monitoring procedures and take the appropriate protective action in the event of a release.

3.3 Protective Actions

The protective actions required to reduce the dose from the non-dairy food pathway will vary with the severity of the accident and the time of year of the accident. The most significant mechanism for the contamination of crops is the direct deposition of radionuclides from the passing plume.

Other pathways discussed in Section 2 can potentially cause contamination of crops; however, there is significant time delay and/or dilution inherent in these mechanisms which will mitigate the consequences of a given accident.

There are several possible protective actions which may be taken to give some protection against directly deposited radioactivity. Precautionary protective actions may be based upon information obtained from the facility that a radioactive release to the environment may occur or has occurred and projected deposition patterns. Examples of precautionary protective actions are: 1) sheltering milk producing animals; 2) placing milk and/or meat producing animals on stored feed and covered water; or 3) thoroughly washing leafy vegetables, fruit, or produce before consumption. Preventive and emergency protective actions can not be taken until laboratory measurements have verified that the derived response levels for the preventive or emergency PAGs have been exceeded. Examples of preventive and emergency protective actions are: 1) allowing for decay of short-lived radionuclides; 2) washing the edible material to remove easily removable surface deposits such as particulates; 3) condemning the foodstuff; or 4) bringing in foodstuffs from uncontaminated areas.[7]

Protective actions to ensure contaminated water does not reach the public water supplies include: 1) close the intake from a contaminated river or lake water supply to allow diversion and use of only the uncontaminated water supplies already in the system; 2) draw water from least contaminated reservoir levels since radionuclides may not be homogeneously mixed in large reservoirs; or 3) chemically treat raw water at the treatment facility to reduce radionuclide concentrations to an acceptable level. Depending on the radionuclides present and their concentrations, a time delay at the treatment facility before allowing water to go to domestic water supplies may be adequate to reduce concentrations to an acceptable level.[23]

The necessity of taking protective actions to prevent public consumption of contaminated water supplies is unlikely since the accident sequences

which would result in major releases to water pathways are very remote possibilities. In addition, there will be significant reduction in the radionuclide concentration by dilution in the water course and chemical treatment (the normal treatment given to community water supplies which are taken from surface water sources) prior to public consumption; these may also reduce the radioiodine and strontium. However, there would be little effect on the concentration of cesium and no effect on the concentration of tritium with these treatment methods. Modifying existing water treatment facilities to receive adjunct chemical treatment to specifically remove potential radionuclide contaminants is not considered a feasible alternative.

If water contaminated at unacceptable levels reaches domestic supplies, the following protective actions could be taken: 1) substitution of bottled water or soft drinks; 2) use of water in tanks filled prior to contamination, i.e., hot water tanks; 3) use of uncontaminated water brought in from outlying communities or areas not impacted by the radiological emergency; and 4) use of water that has been chemically treated, such as by a domestic zeolite water softening process.[23] The last method would still require water monitoring prior to use.

3.3.1 Protective Action Decision-Making. After the assessment team has determined and verified that the protective action recommendations (PARs) and protective actions (PAs) for the plume EPZ are appropriate and adequate, they should address the need for an ingestion planning zone (IPZ) PAR. The assessment team and decision-making personnel can make precautionary PAs based upon projections of the ground deposition area and knowledge that a radioactive release may occur or has occurred. The decision-makers, however, can not make IPZ PARs or PAs until actual field measurements or laboratory measurements have verified that the derived response levels for the preventive or emergency PAGs have been exceeded. The following discussion points provide a method for developing the preliminary information base necessary for the decision-maker's use during the formulation of the initial preventive and emergency PARs and PAs:

1) Depending upon the release composition, duration and meteorological conditions, field monitoring should be concentrated to confirm/deny the presence of significant ground contamination a points 5, 10, and 15 miles downwind. Measurements should be taken in the downwind sectors (determined at the facility) and in at least one sector on each side; if the downwind sector is ENE, take measurements in ENE, NE, and E at 5, 10 and 15 miles;

2) If significant contamination is measured, then measurements should be taken in the adjacent sector at approximately the same distance, e.g., if the downwind sector was ENE and contamination was determined in NE and not in E, then take other measurements in NNE. Proceed to adjacent sectors until negative verification is received;

3) Proceed with initial monitoring efforts outward in 5-mile increments in all appropriate sectors (sectors with significant contamination) until measurements are down below the preventive PAG derived response levels;

4) Develop appropriate preventive PAR/PA, e.g., preventive PA in (#) sectors out to (#) miles; and

5) Then develop a detailed sampling plan with appropriate priorities, i.e., milk pathway, mature/perishable crops, etc., to determine the full extent of the area that may exceed the preventive or emergency PAGs.

3.4 Information and Planning Needs to Develop a Site Monitoring System

Before an adequate monitoring plan can be prepared, input data on the specific local situation must be assembled. The following are the minimum

information needs[a] for the area within the ingestion EPZ.

For non-dairy food:

1. The number, type, size, and location of farms (information on dairy farms and cattle feeding practices should be available to implement milk monitoring as described in the Phase 2 document[3], if milk contamination is used to predict vegetation concentrations).

2. The growing season and time of harvest for various crops grown on each farm.

3. The end use of food produced on each farm, (determine what percentages of the food produced are sold for processing or sold at roadside stands).

4. The distribution of food sold for processing. Determine how and where the food is transported for processing and/or marketing.

For water:

1. The number, type, size, and location of water storage facilities. Determine if the storage facilities are open, such as a lake or reservoir, or covered, such as storage tanks.

2. The location of incoming water to storage facilities. Determine if the water coming into reservoirs is from a river or stream that could be contaminated.

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a There is no need for great accuracy because such conditions change frequently; utilize the utility's annual land use census.

3. The water supply in the system that would be protected from contamination, i.e., not open to the environment. Determine how long this supply will last under normal use.

4. The delay time of water between storage and public consumption.

5. The water treatment facilities. Determine if existing chemical treatment will reduce radionuclide concentrations prior to public distribution. Determine if a specialized chemical treatment can be practically added to the existing water treatment facility for use in radiological emergencies (see Appendix D).

3.5 Survey Team Personnel Considerations

Survey team personnel requirements will be dictated by the number of farms and potentially affected water supply systems within a 50 mile radius surrounding the nuclear facility, using the sampling techniques described in Section 4.2. Part of the personnel needed for survey teams may come from the plume exposure rate verification monitoring teams. Personnel for water monitoring may come from the water utility. If additional personnel are required for food and water monitoring, the requirements should be met in accordance with criterion J.11[a] in NUREG-0654.[6]

The emergency planner should select any additional emergency monitoring personnel needed from within the community. These monitoring personnel should be familiar with the local agricultural practices and, ideally, they should be selected from Department of Agriculture personnel. Staff

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a J.11. Each State shall specify the protective measures to be used for the ingestion pathway, including the methods for protecting the public from consumption of contaminated foodstuffs. This shall include criteria for deciding whether dairy animals should be put on stored feed. The plan shall identify procedures for detecting contamination,

(footnote continued)

from the reactor facility who have no radiological emergency assignment may also be used on monitoring teams. State or local police should not be assigned to monitoring teams, since they will be needed for other emergency functions. If personnel requirements cannot be met from these resources, the DOE Regional Coordination Office will provide, upon request, survey teams from available Federal resources through the Federal Radiological Monitoring and Assessment Plan (FRMAP, see Appendix C). Actually, if a power plant accident is of the magnitude being considered here, there is little doubt that emergency monitoring teams would be dispatched as soon as practicable.

The emergency planner should make provisions for mobilizing, equipping, and training all local emergency monitoring personnel. Exercises and drills should be conducted to demonstrate that all emergency response personnel are adequately trained and that training is maintained.

3.6 Evaluation of Sampling and Monitoring Procedures and Instrument Systems

Determination of the levels of contamination after an accident severe enough to result in doses from the non-dairy food and water pathway

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(footnote continued)

for estimating the dose commitment consequences of uncontrolled ingestion, and for imposing protection procedures such as impoundment, decontamination, processing, decay, product diversion, and preservation. Maps for recording survey and monitoring data, key land use data (e.g., farming), dairies, food processing plants, water sheds, water supply intake and treatment plants and reservoirs shall be maintained. Provisions for maps showing detailed crop information may be made by including reference to their availability and location and a plan for their use. The maps shall start at the facility and include all of the 50-mile ingestion pathway EPZ. Up-to-date lists of the name and location of all facilities which regularly process milk products and other large amounts of food or agricultural products originating in the ingestion pathway Emergency Planning Zone, but located elsewhere, shall be maintained.

approaching the preventive PAGs would be difficult. Such an accident would deposit a mixture of radionuclides whose composition would be unknown. Most radionuclides emit characteristic gamma rays along with beta particles, although a few nuclides are pure beta emitters. At present there are no field methods readily available to local emergency monitoring personnel to determine accurately the concentration of two of the important pure beta emitters, Sr-89 and Sr-90. Gross beta-gamma surveys could give an estimate of total surface contamination, but these measurements would not be sufficient to determine the individual radionuclide concentrations which would be necessary for making dose commitment projection. A valid analysis of the gamma emitters would require the use of spectrometric methods using sophisticated equipment. A discussion of analytical problems, instrument systems and options for sampling and analysis is presented below.

3.6.1 Non-Dairy Food Pathway Analytical Problems. Emergency field monitoring for a radionuclide mixture of iodine, cesium, and strontium poses very complex problems. Strontium nuclides of concern are pure beta emitters and are not easily measured in the field. Cesium nuclides decay with characteristic gamma ray energies, which makes field monitoring potentially possible. If cesium is the lone gamma emitter, a calibration curve could be constructed to account for the presence of Cs-134 and Cs-137. This calibration curve could then be used with gross counters. However, the radioiodines would likely overwhelm the gamma ray spectra present on vegetation samples taken shortly after an accident. This is because of: 1) the potential for a greater release of iodine than particulates; 2) a higher deposition velocity for iodine than for particulates; and 3) the complex mixture of gamma energies associated with the radioiodine isotopes: the longer-lived isotopes; i.e., I-131 and I-133, would be present for days following an airborne release.

Analysis for strontium on vegetation samples requires complicated wet chemistry procedures. The classical radiochemical method involves separation of strontium from its yttrium daughters. New yttrium daughters are allowed to grow into the strontium fraction, and a second separation and

counting of the ingrown yttrium daughters by beta counting methods are made. The complexity of this method precludes use on an emergency basis in the field, as it takes approximately 3 weeks to obtain accurate results.

New analytical procedures have been developed based on a single strontium separation, where total strontium is counted at two different time intervals. The strontium-89 and strontium-90 concentrations are calculated based on strontium-89 decay and yttrium-90 ingrowth. This procedure is still not practical for emergency field use, but reduces the time period between the start of chemical separations and receipt of final analytical results by approximately two weeks.[24]

Cesium, or cesium in the presence of iodine, can be monitored using gamma ray spectral analysis techniques. Equipment required for these techniques is more complex and expensive than the gross counting equipment readily available in the fields. Scintillation detectors, i.e., NaI(Tl), matched with single or multichannel analyzers, and Ge(Li) detectors or high purity Ge detectors with multichannel analyzers, are required to resolve the contribution of each radionuclide present in the sample.

As shown in Figure 2, the combined spectra of I-131, Cs-134, and Cs-137 contain several major photopeaks. If only single channel analyzers are available, at least three separate counts, with the windows reset between each count, will be required to establish the concentration of each nuclide in the sample. After the raw count data have been accumulated, simultaneous equations will have to be solved before the concentrations of the various nuclides can be unambiguously determined.

Scintillation detectors equipped with multichannel analyzers resolve the problem of multiple counts and readjustment of counting windows. However, multichannel analyzers are considerably more expensive and complex, causing a potential maintenance problem. Also, these instrument systems require skilled and highly trained technicians for their proper operation and maintenance. Except for the well prepared mobile laboratories, these

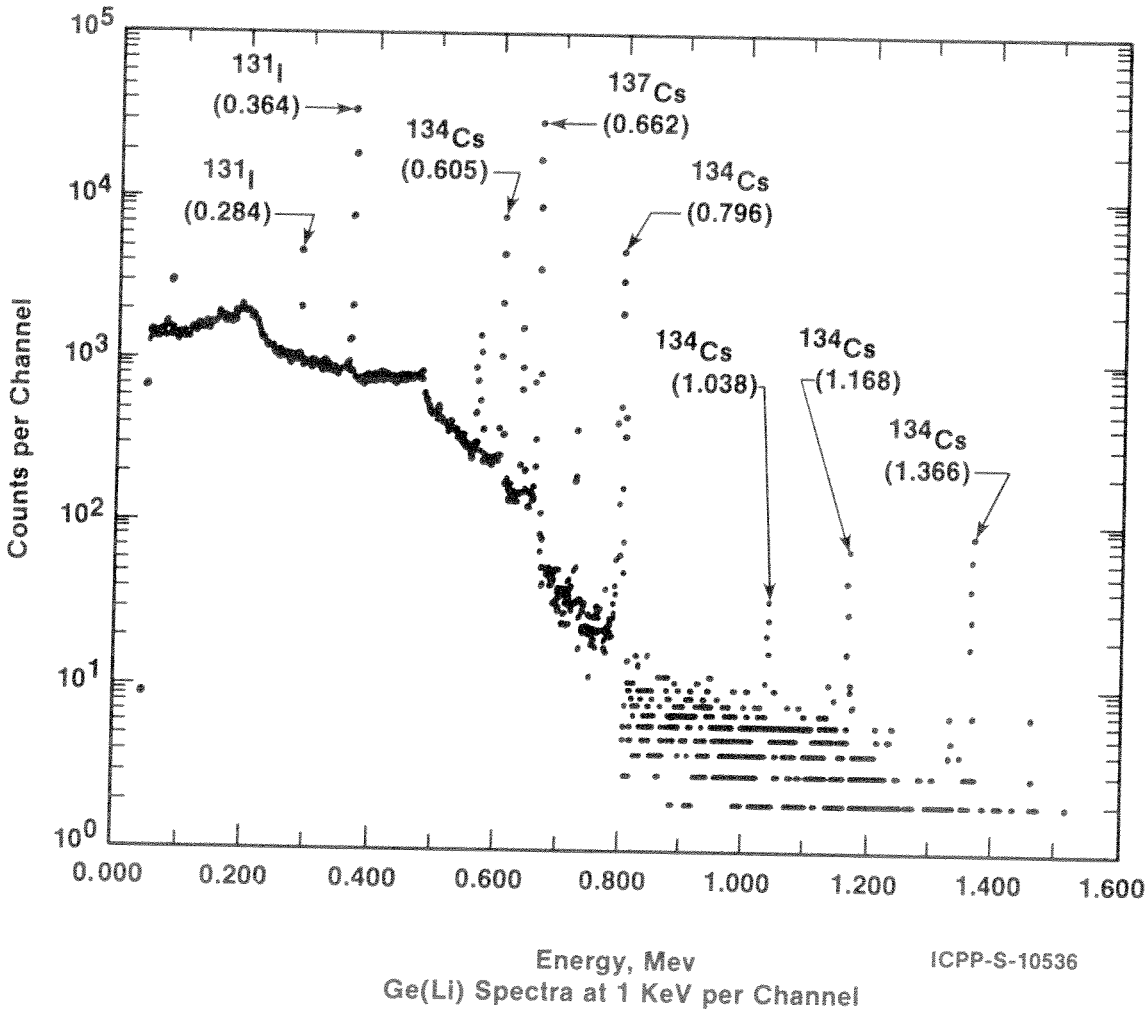

Figure 2. Combined Gamma Spectrum for Iodine-131, Cesium-134, and Cesium-137

instrument systems are not usually intended for emergency field monitoring use. However, such systems are preferred because of the increased speed of analysis and the large number of samples to be evaluated. FRMAP can provide additional counting systems to assist in these types of analyses.

3.6.2 Options for Sampling and Analysis. There are two approaches which can be taken to solve sampling and analytical problems: 1) monitor to the extent possible in the field, and take samples and return to a qualified laboratory for analysis; or 2) return all samples to a qualified laboratory.

All radiation detection equipment (field monitoring and laboratory equipment) should be calibrated using National Bureau of Standards (NBS) traceable primary calibration standards. Secondary sample calibration standards should be prepared in the same size and configuration as the field samples which will be collected and counted for emergency monitoring purposes. Sample calibration standards may be prepared by spiking actual samples (or simulated sample configurations) with measured aliquots of the NBS traceable radionuclide standard. The radionuclides used for the standards should be the same as those longer-lived radionuclides which could be expected to be released from the reactor core, e.g., Cs-134, Cs-137, Sr-89, Sr-90, and I-131. Ba-133 may be substituted for I-131 for preparation of a calibration standard containing a mixture of the above radionuclides, since Ba-133 has lower energy radiations similar to I-131 and a much longer half-life which will be more suitable for a longer term calibration standard. Calibration standards must be counted with each field instrument to determine the detector counting efficiency, e.g., cpm/μCi of activity contained in the calibration sample. Care must be taken to assure that the calibration standards and the field samples are counted in the same geometry in order to maintain the same counting efficiency for each detector.

In order to obtain a derived response level, it is necessary to identify the radionuclides present and determine their concentration levels. An estimate of the contamination levels (and henceforth estimates of the

derived response levels) can be made with gross counting equipment in the field if several assumptions are made. The response or counting efficiency of the gross counters will be dependent on the type and energy of the radiation being measured, as well as geometry (source/detector orientation), absorption of radiation (by the source or environment), and scatter (radiation deflected toward or away from the detector). If the last three parameters are kept constant, i.e., geometry, absorption, and scatter, an assumption can be made about the average source energy and a corresponding efficiency can be used. A given count rate can then be converted to an equivalent concentration of an assumed nuclide. Once the gross gamma measurement has been made and an average equivalent concentration determined for the gamma emitting nuclides of concern, a similar count can be made (if the detector has both beta and gamma detection capability) with the gross counter beta shield open. Thus, the combined beta plus gamma count rate is determined and the previously determined "gamma only" measurements can be subtracted to give a beta count rate. This resultant gross beta count rate could be assumed to contain some contribution from Sr-89 and Sr-90 since both of these nuclides are pure beta emitters without any associated gamma radiation. However, this procedure is subject to extremely large uncertainties because of: 1) potentially large differences between accident source terms; 2) the potential nonuniform distribution of radioactivity in the sample; and 3) large differences in detector efficiencies for counting beta and gamma radiation. Most gamma emitting radionuclides also emit beta particles. If the environmental sample is in a large piece or pieces and the radioactivity is deposited only on the surface, the apparent beta radiation activity will be high with respect to the gamma radiation. If the sample is composed of many small pieces, with each piece having radioactivity deposited on its surface, the sample will appear to have radioactivity uniformly distributed throughout the sample and much of the beta radiation may be absorbed within the sample. This may dramatically increase the apparent ratio of gamma counts to beta counts.

A second field monitoring approach is to use gamma spectral equipment. Scintillation detectors with counting devices capable of resolving emitted

gamma energies can be used by appropriately trained personnel to identify radionuclides and measure their contamination levels at field locations.

The use of this approach would be particularly useful for monitoring those crops whose marketability depends on a quick decision. The emergency planner should make arrangements with the Federal or State agencies which have mobile field gamma spectral capabilities for the use of these instrument systems and trained personnel on an ad hoc basis. However, even if the gamma emitting nuclides are so determined in the field, the beta emitters can only be determined by applying the major assumptions discussed above.

A third alternative involves returning samples to locations equipped for these complicated analyses including strontium. These locations may be mobile laboratories brought to the accident site for the emergency, or may be a State or Federal laboratory (see Appendix C).

A fourth approach is to take both gross field measurements and samples for return to the laboratory for analyses. Future gross field measurements may be related to the decay corrected contamination levels determined at the laboratory. To use this approach, it must be assumed that the gross field measurements indicate the levels and the same radionuclide mix determined by the laboratory. A variety of laboratory determined levels can be used to develop a response curve for the beta gross field measurements. However, care must be exercised in that this response curve will change with time particularly if short-lived nuclides are being measured.

3.6.3 Water Pathway Analytical Problems. The analytical techniques required for water monitoring are similar to those for food monitoring or emergency milk monitoring.[3] On an emergency basis, the most serious problem is contamination of surface water used for a drinking water supply downstream of the accident site, for example, a release of a significant quantity of radioactive material to a river.

The dilution factor (DF) as this material moves downstream can be easily

estimated from the volumetric flow rates of the receiving stream (Q) and the contaminating stream (q).[25] If the receiving stream originally contained negligible quantities of radioactivity, the DF is the ratio of the volumetric flow rate, q, to the sum of the volumetric flow rates, Q plus q. The contaminating stream concentration (C_1) multiplied by the DF yields the resultant downstream concentration (C_2). The DF and C_2 are calculated by the following equations:

$$DF = \frac{q}{Q+q}$$

and

$$C_2 = (DF\ C_1) \text{ or } \left(\frac{q}{Q+q}\right)(C_1)$$

The emergency planner can obtain the volumetric flow rates (Q) for receiving streams that are sources for community water supplies by contacting the State's Department of Water Resources or Department of Water Quality. The Values for "q" and "C_1" should be available from the facility where the release occurs. The emergency planner should determine how long it will take for contamination to arrive at downstream domestic raw water supply intakes. These intakes should be closed until monitoring is completed, if it is suspected that a release has occurred, to determine that the radioactivity levels are below the derived preventive response levels.

Further reduction of the concentration of radionuclides should occur in the water purification plant as a result of conventional treatments such as: 1) coagulation and settling; 2) sand filtration; 3) lime-soda ash softening; and 4) ion exchange.[26] Some water purification plants also have capabilities for less conventional treatments such as: 1) phosphate coagulation; 2) metallic dusts; and 3) clay treatments. Tables D-1 through D-10 show the percentages of radionuclides removed by various water treatment methods.

Timing of emergency water monitoring at the water purification plant will

be dependent upon the flowrate of the river and the upstream distance between the contaminating source and the intake to the purification plant. In any case, surface water monitoring and sampling for confirmatory laboratory analyses should begin within hours of the accident release. Monitoring at the water purification plant also provides the option for use of continuous flowthrough gamma radiation monitors which could be preset to alarm when the detected concentration of radioactive materials approached the derived preventive response levels. This type of monitoring should be quite useful for detecting gamma emitting fresh fission products or other long-lived gamma emitting radionuclides. These alarms could be preset at approximately 70% of the derived response level for the most critical radionuclide expected to be present (e.g., I-131). This would allow time to implement protective actions, such as closing the raw water intakes, before significant quantities of contaminated water have reached the domestic water supply.

4.0 RECOMMENDED MONITORING PROCEDURES AND INSTRUMENT SYSTEMS

Emergency monitoring of surface deposited radioactivity should first be directed toward defining the boundaries, either by ground level field surveys or by aerial measurement surveys, of areas contaminated at or near the preventive response level. After boundaries are defined, non- dairy food and drinking water should be sampled and analyzed by laboratory methods to verify the presence of radioactivity in excess of levels which would lead to doses in excess of the FDA PAGs prior to taking actions which could seriously impact the economic value of the agricultural products in the affected region.

The emergency monitoring plan should call for close coordination and communication with the nuclear power plant operators and should provide for acquisition of laboratory data concerning the plume composition from the preliminary offsite air monitoring. This information can be utilized by the emergency monitoring coordinator to aid in selecting the appropriate non-dairy food and water field monitoring equipment. If cesium is identified on the particulate air filters, then, for emergency purposes, strontium can be assumed to be present in nearly equal quantities. This assumption tends to overestimate the quantity of strontium present because cesium is much the more volatile.

4.1 Field Monitoring Instrumentation

Under emergency conditions, contamination boundaries and radiation field intensities can be determined satisfactorily with portable gross counting equipment. However, portable gross counting equipment cannot be recommended for field identification or quantification of deposited radionuclides. In conjunction with the gross field monitoring, samples of foodstuffs and water selected from the areas of highest radiation measurements (see Section 4.2 for sampling procedures) should be collected and submitted to a laboratory for analyses to identify and quantify the radionuclides. Once this information is acquired, by relating laboratory analyses to field measurements, it may be possible to ascertain, from gross

field measurements, estimates of individual radionuclide surface concentration levels.

A broad selection of equipment is available and marketed for field monitoring as well as for the analytical laboratory. The most sensitive type of portable survey instrumentation is a count ratemeter with a NaI(Tl) scintillation detector. These instruments are very effective as gross gamma detectors; however, they will not detect pure beta emitting radionuclides. This is not a practical problem early on because pure beta emitters would not be released without being accompanied by larger quantities of gamma emitters. Therefore, knowledge of (or assumptions about) the plume composition must be available in order to use the gross gamma survey data as an estimation base for the preliminary radiological assessments and calculated projected doses. Portable gamma spectrometric analyzers are also available. However, they may not be as durable for field use, may have questionable spectral stability under field conditions, may be quite expensive, and require specialized personnel training for proper operation, maintenance, and use.

Other detectors that are useful and can be used with the same count ratemeter used with the NaI(Tl) detector are the thin window (1.5 to 2.0 mg/cm^2 window thickness) GM detectors. These detectors should be operable in both the shielded and unshielded mode. The unshielded detector can be used to detect beta and gamma emitters, whereas, the shielded detector will only detect gamma emitters. The difference between shielded and unshielded detector readings could be related to laboratory analyses of the same samples to provide some general information about contamination levels.

Non-dairy food and water field measurements must not be influenced by the presence of the plume or be complicated by elevated backgrounds caused by surface contamination of nonedible vegetation and soil after passage of the plume. Therefore, edible foodstuff or water samples may have to be taken to a low background area (i.e., uncontaminated area) for counting.

Another monitoring system available to the emergency planner is the Aerial Measuring System (AMS) described in Appendix C.[2] This system ispotentially 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"x2" NaI(Tl) scintillation crystals which are equally distributed within two cargo pods.[27] 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. Whereas, the fixed-wing aircraft detector system has a sensitivity ranging from 1.0 to 10 $\mu Ci/m^2$ for similar gamma energies.[28] However, at gamma energies between 50 to 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 wing aircraft.

The normal data output from AMS is in units of microroentgens per hour ($\mu R/hr$) extrapolated to one meter above ground level.[27] The data from the aerial radiological survey is recorded on magnetic tapes for further data reduction using a ground based computer system. Figure 3 is an example plot of the AMS data.

Tables 9 and 10 contain derived vegetation surface contamination concentrations which may produce ingestion dose commitments at the preventive PAG level for the maximum exposed individual (see Appendix A for assumptions and calculational methods). From Tables 9 and 10 it may be readily determined that, with the exception of a few longer-lived radionuclides such as Co-60, Cs-134, Cs-137, and Ce-144, the helicopter mounted detector system should be adequate for detecting the presence of the majority of the gamma emitting radionuclides at areal concentrations which are equivalent to their derived preventive response levels. A large number of gamma emitting radionuclides will also be detectable by use of the fixed-wing

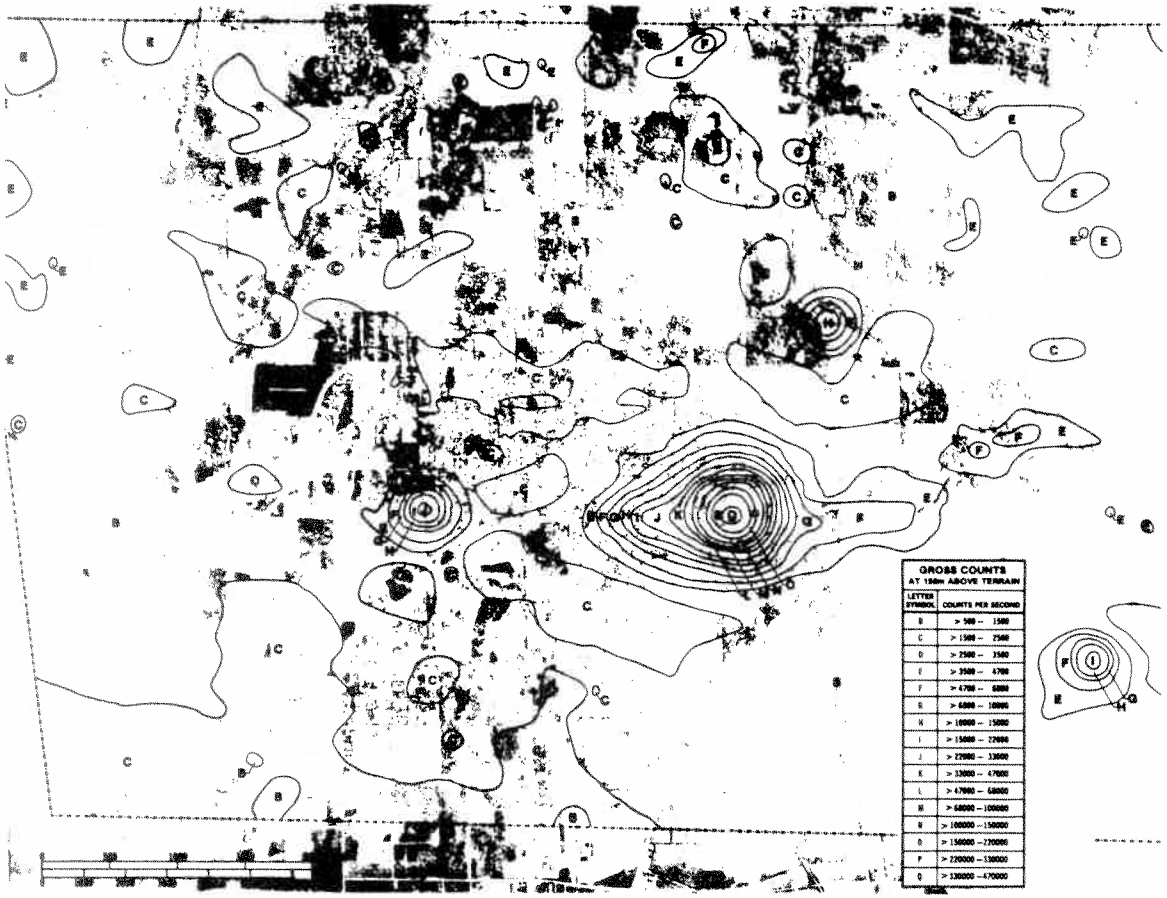

Figure 3. AMS Plot (Example)

TABLE 9

Long-Term Derived Vegetation
Surface Contamination Concentrations
Which May Produce Ingestion Dose Commitments
at the Preventive PAG Level[a]

	Adult		Teen		Child	
Nuclide	Produce[b,c] μCi/m²	Leafy[d] μCi/m²	Produce μCi/m²	Leafy μCi/m²	Produce μCi/m²	Leafy μCi/m²
I-131	1.8E-1[e]	1.4E+0	9.2E-2	1.3E+0	4.7E-2	9.4E-1
I-132	3.5E+1	2.7E+2	2.2E+1	3.2E+2	9.7E+0	2.0E+2
I-133	6.8E+0	5.3E+1	4.2E+0	6.1E+1	1.8E+0	3.7E+1
Rb-86	1.8E+0	1.4E+1	2.2E+0	3.2E+1	9.3E-1	1.9E+1
Cs-134	3.3E-2	2.6E-1	9.4E-3	1.4E-1	5.9E-3	1.2E-1
Cs-136	2.1E+0	1.7E+1	1.3E+0	1.9E+1	8.5E-1	1.7E+1
Cs-137	3.2E-2	2.5E-1	1.1E-2	1.5E-1	6.0E-3	1.2E-1
Te-127m	2.4E-1	1.9E+0	1.4E-1	2.0E+0	8.0E-2	1.6E+0
Te-131m	6.8E+0	5.4E+1	5.0E+0	7.2E+1	5.7E+0	1.1E+2
Te-132	2.9E+0	2.3E+1	2.6E+0	3.7E+1	4.9E+0	9.9E+1
Sb-127	2.8E+0	2.2E+1	2.4E+0	3.6E+1	4.8E+0	9.6E+1
Sr-89	1.1E+0	9.0E+0	2.6E-2	3.7E-1	1.0E-2	2.1E-1
Sr-90	2.8E-3	2.2E-2	1.9E-4	2.8E-3	1.1E-4	2.3E-3
Ba-140	1.3E+0	1.1E+1	1.0E+0	1.5E+1	6.7E-1	1.4E+1
Mo-99	2.6E+1	2.0E+2	1.5E+1	2.2E+2	9.0E+0	1.8E+2
Ru-103	8.4E-1	6.6E+0	7.0E-1	1.0E+1	9.6E-1	1.9E+1
Ru-106	1.4E-2	1.1E-1	1.1E-2	1.6E-1	1.4E-2	2.9E-1
Rh-105[f]	3.4E+1	2.6E+2	3.0E+1	4.4E+2	5.8E+1	1.2E+3
Co-58	6.7E-1	5.3E+0	6.2E-1	8.9E+0	9.6E-1	1.9E+1
Co-60	5.1E-2	4.0E-1	4.6E-2	6.6E-1	7.0E-2	1.4E+0
Y-90	1.9E-2	1.5E-1	1.4E-2	2.0E-1	1.7E-2	3.4E-1
Y-91	1.6E-1	1.2E+0	1.2E-1	1.7E+0	1.5E-1	3.1E+0
Zr-95	3.5E-1	2.8E+0	3.0E-1	4.3E+0	4.1E-1	8.4E+0
Zr-97	9.6E+0	7.6E+1	6.5E+0	9.4E+1	6.6E+0	1.3E+2
Nb-95	9.7E-1	7.7E+0	8.6E-1	1.2E+1	1.3E+0	2.6E+1
La-140	6.0E-1	4.8E+0	4.7E-1	6.7E+0	5.7E-1	1.2E+1
Ce-141	9.1E-1	7.2E+0	7.2E-1	1.0E+1	9.0E-1	1.8E+1
Ce-143	1.1E+1	9.0E+1	8.3E+0	1.2E+2	9.3E+0	1.9E+2
Ce-144	1.7E-2	1.3E-1	1.3E-2	1.9E-1	1.6E-2	3.3E-1
Pr-143	1.3E+0	1.0E+1	9.9E-1	1.4E+1	1.2E+0	2.5E+1
Nd-147	1.8E+0	1.5E+1	1.4E+0	2.1E+1	1.8E+0	3.6E+1
Np-239	1.3E+1	1.0E+2	9.3E+0	1.3E+2	1.1E+1	2.2E+2
Pu-238[f]	2.8E-4	2.2E-3	2.2E-4	3.2E-3	1.3E-4	2.6E-3
Pu-239[f]	2.4E-4	1.9E-3	1.9E-4	2.6E-3	1.1E-4	2.2E-3
Pu-240[f]	2.4E-4	1.9E-3	1.9E-4	2.6E-3	1.1E-4	2.2E-3
Pu-241[f]	1.2E-2	9.6E-2	9.0E-3	1.3E-1	5.4E-3	1.1E-1
Am-241[f]	4.8E-5	3.8E-4	3.6E-5	5.2E-4	2.2E-5	4.4E-4
Cm-242[f]	5.8E-3	4.6E-2	4.4E-3	6.2E-2	2.6E-3	5.2E-2
Cm-244[f]	9.8E-5	7.8E-4	7.4E-5	1.1E-3	4.4E-5	8.8E-4

TABLE 9 (cont'd)

Long-Term Derived Vegetation
Surface Contamination Concentrations
Which May Produce Ingestion Dose Commitments
at the Preventive PAG Level[a]

	Adult		Teen		Child	
Nuclide	Produce[b,c] $\mu Ci/m^2$	Leafy[d] $\mu Ci/m^2$	Produce $\mu Ci/m^2$	Leafy $\mu Ci/m^2$	Produce $\mu Ci/m^2$	Leafy $\mu Ci/m^2$

a Based on an assumed ingestion period equivalent to the shorter time interval of the radionuclide mean lifetime or 365 days (see Appendix A). Ingestion rates for both vegetation types are given in Reference 9 for the maximum exposed individual. Produce and leafy vegetables are assumed to be harvested, fresh frozen, canned, or stored shortly after a contaminating event.

b Produce - vegetables, fruits, and grains.

c The agricultural productivity by unit area of 2 kg/m^2, used in these calculations, is an average value. Actual values should be taken into account when they are known for a specific geographic area. Also, the fraction of the plant area that is edible must be taken into account. This fraction was assumed to be 1.0 for these calculations. The areal activities in this Table do not apply to root crops if the harvest is not in progress and the produce is not on the ground surface during the accidental release of radioactivity. The areal activities in this Table are not equivalent to the initial deposition activity on the ground or other flat surfaces. In order to estimate the initial deposition activity, the values in this table should be multiplied by a factor of 2 to account for the 0.5 retention factor[9] for deposition on vegetation.

d Leafy = Leafy vegetables.

e $1.8E-1 = 1.8 \times 10^{-1} = 0.18$.

f Adult dose conversion factors (DCF's) were obtained from ICRP-30;[10,11,12] dose conversion factors for other age groups were estimated by multiplying these adult DCF's by DCF ratios $\left(\frac{\text{other age group}}{\text{adult}}\right)$ presented in Reference 9 for other nuclides having similar critical organs and retention times.

TABLE 10

Short-Term Derived Vegetation
Surface Contamination Concentrations
Which May Produce Ingestion Dose Commitments
at the Preventive PAG Level[a]

	Adult		Teen		Child	
Nuclide	Produce[b,c] $\mu Ci/m^2$	Leafy[d] $\mu Ci/m^2$	Produce $\mu Ci/m^2$	Leafy $\mu Ci/m^2$	Produce $\mu Ci/m^2$	Leafy $\mu Ci/m^2$
I-131	2.5E-1[e]	2.0E+0	1.3E-1	1.9E+0	6.6E-2	1.3E+0
I-132	4.1E+1	3.2E+2	2.6E+1	3.7E+2	1.1E+1	2.3E+2
I-133	7.1E+0	5.6E+1	4.4E+0	6.4E+1	1.9E+0	3.8E+1
Rb-86	3.5E+0	2.8E+1	4.3E+0	6.2E+1	1.8E+0	3.6E+1
Cs-134	5.3E-1	4.2E+0	1.5E-1	2.2E+0	9.4E-2	1.9E+0
Cs-136	3.5E+0	2.8E+1	2.2E+0	3.2E+1	1.4E+0	2.9E+1
Cs-137	5.7E-1	4.5E+0	1.9E-1	2.8E+0	1.1E-1	2.2E+0
Te-127m	1.5E+0	1.2E+1	8.7E-1	1.3E+1	5.1E-1	1.0E+1
Te-131m	7.2E+0	5.7E+1	5.3E+0	7.7E+1	6.0E+0	1.2E+2
Te-132	3.3E+0	2.6E+1	3.0E+0	4.3E+1	5.7E+0	1.2E+2
Sb-127[f]	3.2E+0	2.6E+1	3.0E+0	4.2E+1	5.6E+0	1.1E+2
Sr-89	4.1E+0	3.2E+1	9.1E-2	1.3E+0	3.7E-2	7.5E-1
Sr-90	5.0E-2	3.9E-1	3.5E-3	5.0E-2	2.1E-3	4.2E-2
Ba-140	2.2E+0	1.7E+1	1.7E+0	2.5E+1	1.1E+0	2.2E+1
Mo-99	2.9E+1	2.3E+2	1.7E+1	2.5E+2	1.0E+1	2.1E+2
Ru-103	2.5E+0	2.0E+1	2.1E+0	3.0E+1	2.8E+0	5.7E+1
Ru-106	2.1E-1	1.6E+0	1.6E-1	2.3E+0	2.0E-1	4.3E+0
Rh-105[f]	3.6E+1	2.8E+2	3.2E+1	4.6E+2	6.2E+1	1.3E+3
Co-58	3.0E+0	2.4E+1	2.8E+0	4.0E+1	4.3E+0	8.7E+1
Co-60	8.8E-1	6.9E+0	7.9E-1	1.1E+1	1.2E+0	2.4E+1
Y-90	3.4E-1	2.7E+0	2.5E-1	3.7E+0	3.0E-1	6.1E+0
Y-91	6.1E-1	4.8E+0	4.7E-1	6.8E+0	5.9E-1	1.2E+1
Zr-95	1.5E+0	1.2E+1	1.3E+0	1.8E+1	1.7E+0	3.5E+1
Zr-97	9.9E+0	7.8E+1	6.7E+0	9.7E+1	6.8E+0	1.4E+2
Nb-95	2.7E+0	2.1E+1	2.4E+0	3.4E+1	3.4E+0	7.0E+1
La-140	9.9E-1	7.8E+0	7.7E-1	1.1E+1	9.3E-1	1.9E+1
Ce-141	2.4E+0	1.9E+1	1.9E+0	2.7E+1	2.3E+0	4.7E+1
Ce-143	1.2E+1	9.6E+1	8.9E+0	1.3E+2	1.0E+1	2.0E+2
Ce-144	2.3E-1	1.8E+0	1.8E-1	2.5E+0	2.2E-1	4.5E+0
Pr-143	2.2E+0	1.7E+1	1.7E+0	2.4E+1	2.1E+0	4.2E+1
Nd-147	2.7E+0	2.2E+0	2.2E+0	3.2E+1	2.8E+0	5.7E+1
Np-239	1.4E+1	1.1E+2	1.0E+1	1.5E+2	1.2E+1	2.5E+2
Pu-238[f]	5.2E-3	4.0E-2	4.0E-3	5.8E-2	2.4E-3	4.8E-2
Pu-239[f]	4.4E-3	3.6E-2	3.4E-3	4.8E-2	1.9E-3	4.0E-2
Pu-240[f]	4.4E-3	3.6E-2	3.4E-3	4.8E-2	1.9E-3	2.0E+0
Pu-241[f]	2.2E-1	1.7E+0	1.6E-1	2.4E+0	9.8E-2	2.0E+0
Am-241	8.6E-4	6.8E-3	6.4E-4	9.4E-3	3.8E-4	7.8E-3
Cm-242[f]	4.6E-2	3.6E-1	3.4E-2	5.0E-1	2.0E-2	4.2E-1
Cm-244[f]	1.8E-3	1.4E-2	1.3E-3	1.98E-2	7.8E-4	1.6E-2

TABLE 10 (cont'd)

Short-Term Derived Vegetation
Surface Contamination Concentrations
Which may Produce Ingestion Dose Commitments
at the Preventive PAG Level[a]

	Adult		Teen		Child	
Nuclide	Produce[b,c] $\mu Ci/m^2$	Leafy[d] $\mu Ci/m^2$	Produce $\mu Ci/m^2$	Leafy $\mu Ci/m^2$	Produce $\mu Ci/m^2$	Leafy $\mu Ci/m^2$

a Based on an assumed ingestion period equivalent to the shorter time interval of the radionuclide mean effective lifetime (includes weathering and radioactive decay) or 30 days following a contamination event (see Appendix A). Ingestion rates for both vegetation types are given in Reference 9 for the maximum exposed individual. Produce and leafy vegetables are assumed to remain in the garden or field until the time of consumption.

b Produce - vegetables, fruits, and grains.

c The agricultural productivity by unit area of 2 kg/m^2, used in these calculations, is an average value. Actual values should be taken into account when they are known for a specific geographic area. Also, the fraction of the plant area that is edible must be taken into account. This fraction was assumed to be 1.0 for these calculations. The areal activities in this Table do not apply to root crops if the harvest is not in progress and the produce is not on the ground surface during the accidental release of radioactivity. The areal activities in this Table are not equivalent to the initial deposition activity on the ground or other flat surfaces. In order to estimate the initial deposition activity, the values in this table should be multiples by a factor of 2 to account for the 0.5 retention factor[9] for deposition on vegetation.

d Leafy = Leafy vegetables.

e 2.6E-1 = 2.6×10^{-1} = 0.26.

f Adult dose conversion factors (DCF's) were obtained from ICRP-30;[10,11,12] dose conversion factors for other age groups were estimated by multiplying these adult DCF's by DCF ratios $\left(\frac{\text{other age group}}{\text{adult}}\right)$ presented in Reference 9 for other nuclides having similar critical organs and retention times.

aircraft system, however, this system's sensitivity is an order of magnitude less than that of the helicopter mounted 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.[27] 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 contaminated foodstuffs and other non-food producing areas; 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.

Field monitoring instrumentation for water should be similar to the recommended for emergency milk monitoring.[3] Also, similar methods could be used, i.e., immersion counting or ion exchange resin counting. The immersion counting method requires a twenty liter liquid sample in a 5 gallon "Jerri Can" container (see Figure E-1). A plastic tube sealed at the bottom is placed inside the container and the radiation detector probe is inserted inside the plastic tube midway into the container. This provides the optimum geometry for field counting of the bulk liquid sample. The ion exchange resin counting method, as described in the Phase 2 document,[3] concentrates the radioactivity and thus requires a smaller sample volume. The anion resin column can be used selectively to collect the radioiodines for counting and a cation exchange resin will collect the radiostrontiums and radiocesiums. The resins can be directly gamma counted to determine the radioiodine and radiocesium activity. However, the radiostrontium must be removed from the resin and precipitated for beta counting.

4.1.1 Detection Limit Requirements for Field Monitoring Instruments. There is a level of detection below which the activity from radionuclides in environmental samples cannot be distinguished from background activity.

The level where the environmental and background activities can be distinguished from each other is called the minimum detectable level (MDL) of activity (i.e., sensitivity). The MDL varies for each instrument and radionuclide. Therefore instruments with MDLs greater than the preventive response levels for the nuclides and sample type being monitored should not be used for emergency environmental monitoring of non-dairy foods and water. Also, the emergency monitoring personnel should be aware that the instrument MDLs are a function of the background count rate, and that the MDL for an individual instrument will increase if the background count rate increases. This is why the environmental samples must be taken to uncontaminated, low background locations for counting with the radiation detection instruments.

Table 11 shows I-131 MDLs for several instruments using the immersion monitoring method. As this table shows, of those instruments listed, only the Victoreen Thyac III ratemeter with the model 489-55 NaI(Tl) 1.25"x1.5" detector appears capable of detecting the preventive response level concentration of I-131 in water (0.025 μCi/L or 0.013 μCi/L).

TABLE 11

Minimum Detectable Level of Sensitivity for I-131 Using a Victoreen Thyac III Ratemeter with GM and NaI(Tl) Probes

Probe	Minimum Detectable Countrate (cpm)	MDL (μCi 131-I/L)
489-55 NaI(Tl) (1.25"x1.5")	215[a]	7.6×10^{-4}
491-3 GM	28[a]	0.053
489-4 GM	24[a]	0.037

[a]Calculated from averages of two instrument systems (See Appendix E).

From Tables 2 and 3, it can be determined that the derived preventive response levels for all the other gamma emitting radionuclides are at concentrations which are higher than that of I-131. Most of these radionuclides have gamma energies and relative gamma ray abundances which are equivalent to or greater than that of I-131. Therefore, any instrument equivalent to the Victoreen Thyac III ratemeter with a 1.25"x1.5" NaI(Tl) detector should be sufficiently sensitive to detect any of the gamma emitting radionuclides at their derived preventive response levels. Further discussion of the method for calculating MDLs and additional instrument data are presented in Appendix E.

For each instrument type used in field monitoring, there will be a need to correlate the instrument response for ground level measurements (1 to 7.5 cm above ground) or immersion measurements for water to the derived response levels for the preventive or emergency PAGs. The MDLs for the field monitoring instruments must be less than the derived response level for the preventive PAG. Tables 2, 3, 4, 5, 9, and 10 (derived response levels) and the appropriate efficiency factors for each instrument may be used to calculate the instrument response which is equivalent to the derived response level. The following example illustrates the general method for calculating the instrument response.

$$\text{cpm} = \frac{\text{Derived Response Level } (\mu\text{Ci/L, m}^2 \text{ or kg})}{\text{Efficiency Factor } (\text{cpm}/\mu\text{Ci/L, m}^2 \text{ or kg})}$$

4.2 Emergency Field Sampling Procedures

Concurrent with or immediately following the emergency field contamination surveys, samples of foodstuffs and water need to be collected for detailed laboratory analyses. The emergency planner should set priorities regarding the sampling needs. Samples of foodstuffs and water should first be collected from the areas determined to have the highest levels of surface contamination. Within these areas, if the release is during or

near the harvest season, priority should be given to sampling those above ground foodstuffs which will reach the consumer first. Examples of some of these foodstuffs are: green, leafy vegetables; peppers; tomatoes; melons, etc. Background levels of the long-lived radionuclides (cesium and strontium) should be determined in foodstuff samples collected from the same general geographic area, but outside the plume deposition area. Emergency sample collection and handling procedures should follow the procedures established for routine environmental radiological monitoring at nuclear power plants [29,30,31] (see Appendix F).

4.2.1 Non-Dairy Food Crop Sampling. Information on the type and quantity (e.g., tons) of non-dairy food crops should be obtained for all farms within the ingestion pathway EPZ which are grown for marketing. (Non-dairy food crops grown in home gardens for family consumption need not be included). The type of crops grown on each farm and where each farm is located within the EPZ should be established. Once the number, location and type of crops grown have been established, information on the growing season for each type of crop, the methods of harvesting, processing procedures, where the crop is marketed and how the crop is transported to market will be needed. The best sources of information of this type can be obtained through the State and county agricultural agencies, as required.

Information on the effects of weathering, harvesting, and processing on the radioactive contamination of the types of food crops grown within the EPZ should then be determined. Also those crops most likely to be contaminated by a radioactive release from the nuclear power plant should be established. For example, leafy vegetables such as lettuce, cabbage, kale, and endive are much more likely to retain radioactivity from a release than potatoes, carrots, or turnips which are grown beneath the ground. Also the uptake of radioactivity by these various food crops, over a period of several weeks prior to harvesting, should be obtained (See NRC Regulatory Guide 1.109).

With the above information, the need to monitor non-dairy food crops can

be determined should a radioactive release involving particulates and halogens occur within the EPZ; depending on the time of year and when these crops are harvested. If the type of crop has not been planted or harvesting will not occur for 30 days or more, these types of crops can be ignored in developing a monitoring plan during the emergency phase of the accident. The monitoring of crops harvested more than 30 days after the accident or determining whether it is safe to plant crops in soil which has been contaminated by the radioactive release, is a long-term problem in monitoring in the ingestion pathway and will be covered in guidance on recovery and reentry of the offsite environment.

Once the location of all of the farms growing non-dairy food crops and the type or types of crops has been determined, the location of each farm should be plotted on maps covering the ingestion pathway EPZ. National Topographical Geodetic Maps illustrating physiographic features or some similar type maps with a scale of approximately 1:100,000 or about one inch equaling 1.5 miles should provide adequate detail for this purpose. An identification number for each farm should then be provided. The recommended procedure for identifying these farms would be to overlay the maps covering the 50 mile ingestion pathway EPZ with a grid and sector procedure as described in Appendix 4 of NUREG-0654, Rev. 1. This will divide the EPZ into 16 sectors with circular grids with radii at intervals of 2, 5, 7, 10, 15, 20, 30, 40, and 50 miles from the plant or nine grids. The sectors should be lettered A through R (note: letters I and O are not used since they maybe confused with numbers) and the grids numbered 2, 5, 7, . . . indicating the radial distance from the plant. All farms located within these divisions could then be numbered accordingly. For example if a farm was located 16 miles from the plant site in the north, northeast sector of the EPZ, its number would be A-20-1. The next farm located in this sector at between 15 and 20 radial miles from the plant would be numbered A-20-2. The numbering of farms within each grid and sector should be consistent. For example, starting in the lower left hand corner and numbering across the grid in a clockwise direction, from bottom to top. This procedure should then make it easy to locate each farm on the maps by knowing the grid and sector in which the

farm is located as well as approximately where it is located within the grid and sector.

After numbering all the farms within the ingestion pathway EPZ, lists of crops by type should be developed listing all the farms by number which grow that crop for marketing purposes. If an accident occurs, the crops that will be harvested within the next 30 days should be determined and the appropriate lists of farms growing those crops and the EPZ map showing their locations would be used to develop the monitoring plan.

Using an overlay of the ingestion pathway EPZ with the locations of all the farms, determine the path of the release across the EPZ. This plume path should be determined by the dispersion projection of the release by the plant operator or other dose projection systems as confirmed by the monitoring data obtained in monitoring airborne release and/or data obtained by AMS or other aircraft monitoring of the ingestion pathway EPZ. The actual path of the plume as established by measurements is likely to be quite different from that predicted with dispersion calculations. All the farms which have crops that will be harvested within 30 days, should then be identified if they are located within the path of the plume or release. The first type of crop sampled should be those most likely to be contaminated by the plume. Starting with the farms located close to the plant site, obtain samples of each type of crop to be harvested and extend to sampling, farm by farm to the outer grids of the EPZ.

As the results of the analysis of the samples become known it may be necessary to skip over farms in the 10 to 40 mile radius if the results from farms within 10 miles indicate high levels of radioactivity above the preventative response levels. In this situation, sample farms at distances of 45 to 50 miles to determine the extent of the hazardous levels of contamination. Once the extent of the hazard is known, then representative samples should be obtained over the radial distance from the plant and begin sampling farms close to the plant that were outside the plume path to ensure that the area of contamination within the EPZ has been

accurately established. Finally ensure that all farms growing the crops to be harvested within 30 days and located within the area of the plume path are sampled. If this number of farms exceeds 50 or the number of samples for all crops which must be monitored exceeds 200 then aerial surveys and selective sampling techniques to reduce the number of samples may be necessary. However, all farms within two miles of the plant site should be sampled. Also representative sampling of farms outside the plume path should be obtained using random sampling procedures.

It is important to develop a plan for locating and marking sampling locations for samples of food crops within a field. Sampling locations should be preselected so that it is not difficult to re-sample from the location, within 5′ to 10′ of the original sample. This may best be done by taking samples adjacent to readily identified roads or transport routes easily identified by verbal descriptions and accessible by motor vehicles or footpath. The sample should be identified by the farm number on the maps. This is so that a sample location that has a suspect analysis (e.g., within 10% of the derived preventive response levels shown in Table 4) may easily be located for re-sampling, if necessary.

The plan should be consummated, at the first full scale exercise after its development, to determine if modifications to the plan are necessary. Reference locations for sampling sites should be preselected within the EPZ at several distances from the plant within each sector.

The objective of the pre-accident sample collection (sample collection during exercises) and study is to:

1. Acquaint the sampling teams with the geographical or other anomalies that may be prevalent in areas where sampling may be desirable;
2. Allow the sampling team to become familiar with problems in specific areas due to inclement weather;
3. Note background of the areas, where crops are grown, due to world-wide fallout contamination. The background measurements obtained

should be recorded in a logbook for each specific area where samples are taken;

4. Challenge the counting facility with numbers of background crop samples so that they will know the problems to be expected during a "real" event;
5. Note any problems with collection of samples, packaging, need for special tools, storage of samples during transport to counting facility, handling to prevent potential cross-contamination, labeling, etc.;
6. Develop communication procedures between sample collectors and laboratory personnel with respect to drop-off and storage at laboratory site. Facility should be equipped to handle hundreds of samples;
7. Develop procedures for "background" samples with respect to fractionating a sample, storage of remains, preparation for ashing, ashing itself, counting, recording data, waste disposal, analyzing data, etc.;
8. Institute follow-up procedures for positive results. Resampling from positive samples, from faroff distances for the reactor site (e.g., >50 miles) need not be closely identifiable, with regards to exact sampling location, as compared to samples taken at close distances.

Samples should be collected in a sealable plastic bag, sealed, and tagged. Each sample should be double bagged to help prevent cross contamination during transport to the laboratory. All sampling equipment used at a sampling site should be decontaminated prior to re-use at another sampling location to prevent sample cross contamination. The sample tag should contain all the information needed to assure appropriate identification of sample location by farm identification number, type of crop, date collected, time of day, name or person collecting sample, person's affiliation, and any other relevant identification information including dose rate in area.

A measurement should be made of the sample at some remote distance from the collection point with a portable survey meter if the background in the area of the collection is greater than the normal background for that area

(see pre-accident collection item (3) above). If the area background is about normal, the sample measurement should be made after collection, with the best possible geometry. In cases where the dose rate (or count rate) of the sample exceeds background by a factor of two or greater, the information should be called to the attention of the EOC for further instructions.

4.2.2 Non-Dairy Food Sample Preparation. Typically, strontium analyses or other chemical separations require 10 grams of ash for each sample analysis, which may represent initial vegetative samples of up to several kilograms. Table 12 provides data on the number of kilograms of original sample required to provide 10 grams of ash. If gamma spectroscopy is used to identify and quantify the gamma emitting radionuclides, larger quantities of ash (up to 40 grams) are required to produce the desired analytical sensitivity and sample geometry. A four kilogram vegetation sample will usually provide enough ash to determine the radionuclides of interest under normal measurement conditions.[29] Under emergency conditions surface contamination levels may be higher than under normal conditions, thus smaller samples may provide adequate sensitivity. However, the smallest vegetation sample size should not be less than 0.5 kilogram.[32]

4.2.3 Water Sampling. Water monitoring under emergency conditions should be directed toward surface water supplies. Ground water monitoring should be left for the re-entry sampling program because there are many mechanisms which will delay the migration of released radioactivity into the ground water.

Surface water monitoring or sample collection should be performed between the accident site and the diversion point in the water course and also on the purified stream at the water treatment plant. The water course monitoring should give an indication of the severity of the problem and give some lead time before the activity reaches the diversion point. As a rule of thumb, water samples collected from rivers or streams for field monitoring or laboratory analyses should be collected from a depth of 0.4 to

TABLE 12

Kilograms of Food Required for 10 Grams Ash[a]

Item	% Ash	kg Original
Eggs (shelled)	1.0	1.0
Fish	1.5	0.67
Flour	0.45	2.2
Fruit (fresh)	0.7	1.4
Potatoes	1.0	1.0
Poultry	0.9	1.1
Rice	0.41	2.4
Shellfish	1.65	0.61
Vegetables (fresh)	0.72	1.4
Vegetables (root)	0.79	1.3
Wheat	1.7	0.59
Vegetation (hay)	2.3	0.44

NOTE: Percent ash is an average value found in routine work. Variations have been found as large as 25% depending upon particular sample composition and ashing conditions.

[a] Derived from: Harley, J. H., editor, Health and Safety Laboratory (HASL) Procedures Manual, 1972, HASL-300, DOE, revised annually as the Environmental Measurements Laboratory (EML) Procedures Manual.

0.5 of the distance between the surface and bottom of the stream at the stream channel centerline and at a downstream distance from the point discharge equivalent to 10 widths of the receiving stream.[30,33] This allows for uniform mixing from near field turbulence and provides a representative sample for monitoring purposes. For more detailed calculational methods to determine sampling locations based on stream mixing see NRC Regulatory Guide 1.113[34] and NUREG/CR-3332.[35]

Field monitoring for gross gamma contamination can be done by the same methods used for emergency milk monitoring; i.e. the immersion counting method or the ion exchange method.[3] Samples will need to be collected and preserved for laboratory analyses to identify and quantify specific radionuclides (see Appendix F for details on sample preservation). Portable gamma spectrometric analyzers would be usable if the equipment and trained personnel are available for their use. There are no acceptable field methods for Sr-89 and Sr-90 analyses.

The water samples collected for laboratory analyses must be large enough to achieve the desired sensitivity. For routine gamma spectroscopy, a sample size of 3.5 to 4 liters is usually required.[30] If appreciable radioactivity is known or expected to be present, a smaller quantity could be used for emergency monitoring, but the sample should be diluted to a volume which is appropriate for the geometry of the counting system. Usually a 1 liter aliquot is required for the strontium radiochemical analysis; a few milliliters are required for liquid scintillation counting to determine the amount of tritium present.

4.3 Summary

Emergency monitoring of surface deposited radioactivity should first be directed toward defining the boundaries of contaminated areas and later be directed toward quantifying the nature and levels of contamination. Instruments capable of gross radiation measurement are adequate for defining the contaminated area boundaries. However, more sensitive and sophisticated instrumentation, such as NaI(Tl) detectors and single or

multichannel analyzers, are required to identify and quantify the contamination levels of specific radionuclides. Samples of contaminated foodstuffs and surface water must be collected and analyzed under controlled laboratory conditions.

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APPENDIX A - DERIVED PREVENTIVE RESPONSE LEVELS (CONCENTRATION LIMITS) FOR VEGETATION AND DERIVED SOIL AND VEGETATION CONTAMINATION INDICES

Any potential release of radioactive materials from a reactor core will contain a complex mixture of radionuclides. Table A-1 provides a list of the initial radionuclide activities which may be present in the reactor core at the time of a hypothetical accident. These activities were calculated for a 3200 megawatt thermal pressurized water reactor. Due to an estimated delay time of between 0.5 and 30 hours between termination of the chain reaction and the release of the radioactive material, radionuclides with half-lives shorter than 25.7 minutes have been eliminated from the Table.[1]

The number of radionuclides present in a sample and the range of their half-lives complicates the calculation of derived response levels (concentration limits) or surface contamination indicies, i.e., the contamination levels per unit plant surface area ($\mu Ci/m^2$) which would produce radioactive concentrations ($\mu Ci/kg$) on vegetation which are high enough to result in projected dose commitments equivalent to the preventive PAG. The PAG projected dose commitment concept assumes that no protective actions are taken (e.g., vegetables would not be thoroughly cleaned before eating). Therefore, the contamination levels are affected by radioactive decay and weathering removal of the deposited radionuclides. The effective half-life (T_E) is a function of the radiological half-life (T_R) and the weathering half-life (T_W). Their mathematical relationship is:

$$T_E = \frac{T_R \times T_W}{T_R + T_W}$$

and their decay constant relationship is:

$$\lambda_E = \lambda_R + \lambda_W$$

where:

$$\lambda_E = \frac{\ln 2}{T_E}$$

TABLE A-1

Initial Activity of Radionuclides in the Nuclear Reactor Core at the Time of the Hypothetical Accident[a]

Radionuclide	Radioactive Inventory Source (Curies x 10^{-8})	Half-Life (days)
Cobalt-58	0.0078	71.0
Cobalt-60	0.0029	1,920
Krypton-85	0.0056	3,950
Krypton-85m	0.24	0.183
Krypton-87	0.47	0.0528
Krypton-88	0.68	0.117
Rubidium-86	0.00026	18.7
Strontium-89	0.94	52.1
Strontium-90	0.037	11,030
Strontium-91	1.1	0.403
Yttrium-90	0.039	2.67
Yttrium-91	1.2	59.0
Zirconium-95	1.5	65.2
Zirconium-97	1.5	0.71
Niobium-95	1.5	35.0
Molybdenum-99	1.6	2.8
Technetium-99m	1.4	0.25
Ruthenium-103	1.1	39.5
Ruthenium-105	0.72	0.185
Ruthenium-106	0.25	366
Rhodium-105	0.49	1.50
Tellurium-127	0.059	0.391
Tellurium-127m	0.011	109
Tellurium-129	0.31	0.048
Tellurium-129m	0.053	0.340
Tellurium-131m	0.13	1.25
Tellurium-132	1.2	3.25
Antimony-127	0.061	3.88
Antimony-129	0.33	0.179
Iodine-131	0.85	8.05
Iodine-132	1.2	0.0958
Iodine-133	1.7	0.875
Iodine-134	1.9	0.0366
Iodine-135	1.5	0.280
Xenon-133	1.7	5.28
Xenon-135	0.34	0.384

[a] Taken from WASH-1400, Appendix VI. (Assumes a three-region pressurized water reactor core, with an equilibrium core initially charged with 3.3% enriched uranium, at a time when the three regions have average burnups of 880, 17,600, and 26,400 megawatt-days per metric ton of uranium charged.)

TABLE A-1 (Cont'd)

Radionuclide	Radioactive Inventory Source (Curies x 10^{-8})	Half-Life (days)
Cesium-134	0.075	750
Cesium-136	0.030	13.0
Cesium-137	0.047	11,000
Barium-140	1.6	12.8
Lanthanim-140	1.6	1.67
Cerium-141	1.5	32.3
Cerium-143	1.3	1.38
Cerium-144	0.85	284
Praseodymium-143	1.3	13.7
Neodymium-147	0.60	11.1
Neptunium-239	16.4	2.35
Plutonium-238	0.00057	32,500
Plutonium-239	0.00021	8.9×10^6
Plutonium-240	0.00021	2.4×10^6
Plutonium-241	0.034	5,350
Americium-241	0.000017	1.5×10^5
Curium-242	0.0050	163
Curium-244	0.00023	6,630

$$\lambda_R = \frac{\ln 2}{T_R}$$

$$\lambda_W = \frac{\ln 2}{T_W}$$

Calculation of the derived preventive response levels (concentration limits) for a single contaminating event involves the conservative assumption that contaminated leafy vegetables and produce are ingested for time periods from 30 days up to a full year following the contaminating event. U. S. NRC Regulatory Guide 1.109[2] and FDA[3] dose conversion factors (DCFs) are used to back calculate the total annual dose commitment from ingested activity. These DCFs are based on a 50-year dose commitment from a 1-year ingestion period. Since the radionuclides which are potentially available for release (Table A-1) have half-lives which vary from fractions of a day to millenia, the determination of the actual effective ingestion period (i.e., the time period over which the nuclides are ingested) becomes somewhat complicated for the radionuclides which have short half-lives.

There are two approaches that can be used to determine the length of the effective ingestion period. The first approach is to assume that the ingestion period for vegetation is equal to ten effective half-lifes or one year whichever is the shorter time period. Ten effective half-lives are assumed to be the length of time for the radioactivity to decay to insignificant levels, and the one year (365 days) time constraint has been arbitrarily chosen by the authors as a reasonable upper limit for the ingestion period for produce which has been contaminated with long-lived radioactivity and which has been fresh frozen or preserved by canning. Use of this method requires a variable derived response level based upon decay and ingrowth corrections for the time intervals between deposition and ingestion. Thus, there is a continuum of values for the derived response levels with respect to time after deposition.

The second approach utilizes the concept of average lifetime ($\bar{T}$) or in this case mean effective lifetime ($\bar{T}_E$). Average lifetime is another term that is sometimes useful in describing radioactive decay. The equation

for radioactive decay is:

$$N = N_0 e^{-\lambda t}$$

where N_0 = number of original atoms,

N = number of atoms present at time t,

λ = radioactive decay constant in inverse units of time (t^{-1}),

t = time (seconds, minutes, hours, days, etc),

and dt = short interval of time.

The number of atoms decaying during the interval from t to t + dt is N and, since each of these atoms had a lifetime t, the total lifetime associated with this interval is λNt. An integration of this factor over all values of t gives the total lifetime of all N_0 atoms, and a division by N_0 gives the mean lifetime $\bar{T}$. The integral is:[4]

$$\bar{T} = \frac{1}{N_0} \int_0^\infty \lambda N t dt = \int_0^\infty \lambda t e^{-\lambda t} dt = \frac{1}{\lambda}$$

$$\bar{T} = \frac{T}{0.693} = 1.44\ T$$

where T = radiological half-life.

The mean effective lifetime is simply:

$$\bar{T}_E = 1.44\ T_E$$

Use of the mean effective lifetime to determine the length of the effective ingestion period permits the calculation of a single value of the derived response level for each nuclide. Care must be used in calculating $\bar{T}_E$ for certain short-lived radionuclides which have long-lived parent nuclides. In these cases, if the parent nuclide is present in the contamination, the $\bar{T}_E$ for the short-lived radionuclide will appear to be the same as that for the long-lived parent nuclide.

The mean effective lifetime for each radionuclide in water is assumed to be equal to the mean lifetime since the lifetime of parameters affecting concentration, other than radiological half-life, are unknown. For the early emergency accident phase, the effective ingestion period for water is assumed to be equal to five days or the radionuclide's mean lifetime whichever time period is shorter. The five day ingestion period has been chosen as a means of normalizing the effect of radionuclides with a longer than five day effective half-life for the following reasons: 1) the five day period is considered as a reasonable time in which to obtain alternative water supplies or to implement ancillary water treatment methods to reduce the radionuclide concentration, and 2) five days is an adequate time for obtaining accurate laboratory analyses to determine the concentration of gamma emitting radionuclides which will provide the decision maker with a basis for determining the long-term usability of the water supply.

For the long-term assessment of a single contaminating event, the derived response levels correspond to a PAG projected dose resulting from a one year ingestion period. In this situation, the effective ingestion period for water is assumed to be equal to the shorter of the radionuclide's mean lifetime or 365 days.

Table A-2 presents the effective half-life on vegetation, mean effective lifetime on vegetation and mean lifetime for all the nuclides except noble gases listed in Table A-1. For the effective half-life and mean effective lifetime on vegetation calculations, the weathering half-life is assumed to be 14 days.[2]

Derived preventive response levels or surface contamination levels which have been calculated for water and vegetation are presented in Tables 2, 3, 4, 5, 9, and 10. The water and vegetation ingestion rates, retention times, and a number of the dose conversion factors (DCFs) used in these calculations are taken from U. S. Nuclear Regulatory Commission Regulatory Guide 1.109.[2] Dose conversion factors for ingested Cs-134, Cs-137, I-131, Sr-89, and Sr-90 are the same as those used by the Food and Drug

TABLE A-2

Radiological Half-Lives, Mean Lifetimes, Effective Half-Lives on Vegetation, and Mean Effective Lifetime on Vegetation for Typical Radionulcides Found in a Nuclear Reactor Core

Radionuclide	Effective Half-Life on Vegetation (days)	Mean Effective Lifetime on Vegetation (days)	Mean Lifetime (days)	Radiological Half-Life (days)
Cobalt-58	11.69	16.84	102.24	71.00
Cobalt-60	13.90	20.01	2674.80	1920
Rubidium-86	8.01	11.53	26.93	18.70
Strontium-89	11.03	15.89	75.02	52.10
Strontium-90	13.98	20.13	15,880	11,030
Strontium-91	0.39	0.56	0.58	0.40
Yttrium-90[a]	2.24	3.23	3.84	2.67
Yttrium-91	11.32	16.29	84.96	59.00
Zirconium-95	11.53	16.60	93.89	65.20
Zirconium-97	0.68	0.97	1.02	0.71
Niobium-95	10.00	14.40	50.40	35.00
Molybdenum-99	2.33	3.36	4.03	2.80
Technetium-99m	0.24	0.35	0.36	0.25
Ruthenium-103	10.34	14.88	56.88	39.50
Ruthenium-105	0.18	0.26	0.27	0.18
Ruthenium-106	13.48	19.42	527	366
Rhodium-105	1.36	1.95	2.16	1.50
Tellurium-127	0.38	0.55	0.56	0.39
Telluriun-127m	12.41	17.87	157	109
Tellurium-129	0.05	0.07	0.07	0.05
Tellurium-129m	0.33	0.48	0.49	0.34
Tellurium-131m	1.15	1.65	1.80	1.25
Tellurium-132	2.64	3.80	4.68	3.25
Antimony-127	3.04	4.38	5.59	3.88
Antimony-129	0.18	0.25	0.25	0.18
Iodine-131	5.11	7.36	11.59	8.05
Iodine-132[b]	0.09	0.14	0.14	0.09
Iodine-133	0.82	1.19	1.26	0.88
Iodine-134	0.04	0.05	0.05	0.04

TABLE A-2 (Cont'd)

Radionuclide	Effective Half-Life on Vegetation (days)	Mean Effective Lifetime on Vegetation (days)	Mean Lifetime (days)	Radiological Half-Life (days)
Iodine-135	0.27	0.39	0.40	0.28
Cesium-134	13.74	19.79	1080	750
Cesium-136	6.74	9.71	18.72	13.00
Cesium-137	13.98	20.13	15,840	11,000
Barium-140	6.59	9.63	18.43	12.80
Lanthanum-140	1.49	2.15	2.40	1.67
Cerium-141	9.77	14.06	46.51	32.30
Cerium-143	1.26	1.81	1.99	1.38
Cerium-144	13.34	19.21	409	284
Praseodymium-143	6.92	9.97	19.73	13.70
Neodymium-147	6.19	8.92	15.98	11.10
Neptunium-239	2.01	2.90	3.38	2.35
Plutonium-238	13.99	20.15	46,800	32,500
Plutonium-239	14.00	20.16	1.2×10^7	8.9×10^6
Plutonium-240	14.00	20.16	3.4×10^6	2.4×10^6
Plutonium-241	13.96	20.11	7,704	5,350
Americium-241	14.00	20.16	2.16×10^5	1.5×10^5
Curium-242	12.89	18.57	235	163
Curium-244	13.97	20.12	9,547	6,630

a If strontium-90 is present in an airborne release to the environment, yttrium-90 will appear to have an effective half-life and mean effective lifetime on vegetation which corresponds to that of stronitum-90.

b If tellurium-132 is present in an airborne release to the environment, iodine-132 will appear to have an effective half-live and mean effective lifetime on vegetation which corresponds to that of tellurium-132.

Administration for adult and infant age group derived response levels in milk.[3] For those nuclides which did not have DCFs listed in U. S. Nuclear Regulatory Commission Regulatory Guide 1.109[2], i. e., isotopes of americium, antimony, curium, plutonium, and rhodium, adult age group DCFs were obtained from ICRP-30 supplements.[4,5,6] The DCFs for other age groups for the nuclide were estimated by multiplying the adult DCFs by DCF ratios ($\frac{\text{other age group}}{\text{adult}}$) obtained from U. S. Nuclear Regulatory Commission Regulatory Guide 1.109[2] for nuclides having similar critical organs and retention times.

The following assumptions were utilized in deriving the preventive response levels for vegetation and water:

1. Single release duration of 0.5 to 10 hours[1] with no protective action taken (e.g., vegetables or produce are not washed before being eaten).

2. The rate constant for removal of radioactivity on plant or leaf surfaces by weathering corresponds to a 14-day half-life.[2]

3. Produce contamination is assumed to have occurred immediately prior to harvest (e.g., worst case assumptions).

4. The short-term derived response levels for produce and leafy vegetables assumes that both vegetation types are harvested and consummed directly from the garden and radionuclide removal by weathering is taking place. The ingestion period is equivalent to the shorter of the nuclide's mean effective lifetime on vegetation or 30 days.

5. The long-term derived response levels for produce and leafy vegetables are based on the worst case condition were both vegetation types are immediately harvested and fresh frozen or preserved by canning. In this case, weathering is not assumed to have occurred,

and the ingestion period for produce is assumed to be equivalent to the shorter of the radionuclide mean lifetime or 365 days. The 365 day time period has been arbitrarily chosen as a reasonable upper time limit for ingestion of contaminated produce which has been fresh frozen or preserved by canning.

6. Derived response levels were not calculated for those radionuclides which have mean lifetimes that are shorter than 1 day, since the shortest time delay between harvest of vegetation or crops and ingestion by man is 24 hours (1 day) for leafy vegetables.[2]

7. Agricultural productivity by unit area is 2.0 kg/m^2 (wet weight) for produce or leafy vegetables.[2]

8. The daily ingestion rates for leafy vegetables are 0.07, 0.12, and 0.18 kg/day for the child, teenager and adult, respectively. For produce (fruits, vegetables, and grains), the daily ingestion rates are 1.42, 1.73, and 1.42 kg/day for the child, teenager and adult, respectively.[2] These ingestion rates are the Regulatory Guide values for the maximum exposed individual.

9. The effective ingestion period for water during the early emergency accident phase is assumed to be equal to the shorter of the radionuclide's mean lifetime or five days. The five day ingestion period has been arbitrarily chosen as a reasonable upper time limit in which an alternative water supply may be obtained and it is a reasonable time to obtain laboratory analyses from gamma emitting radionuclides.

10. To evaluate the long-term usability of the water supply, the effective ingestion period for water is assumed to be equal to the shorter of the radionuclide's mean lifetime or 365 days.

11. The daily ingestion rates for water are assumed to be 0.9, 1.4, 1.9 and 2.0 liters/day for the infant, child, teenager, and adult respectively.[2] These ingestion rates are the Regulatory Guide values for the maximum exposed individual.

The calculational models for the derived preventive response levels (concentrations) are as follows:

Water (Table 2)

$$C = \frac{(PAG)(10^{-6})}{(IR)(EIT)(DCF)(D)} = \mu Ci/liter$$

where: C = derived preventive response level (concentration)

PAG = preventive protection action guide dose commitment: 1500 mrem for iodines and 500 mrem for all other radionuclides

10^{-6} = conversion factor (μCi/pCi)

IR = daily ingestion rate (liter/day)

DCF = dose conversion factor (mrem/pCi ingested)

EIT = effective ingestion time in days (the shorter of the radionuclide mean lifetime or 5 days) (See Annex 1 to Appendix A)

D = decay correction term, where $D = \frac{1 + e^{-\lambda t}}{2}$; t is the shorter of the nuclide's mean lifetime in days or 5 days; λ = radionuclide decay constant in days^{-1}. (See Annex 1 to Appendix A.)

Water (Table 3)

$$C = \frac{(PAG)(10^{-6})}{(IR)(EIT)(DCF)(D)} = \mu Ci/liter$$

where: EIT = effective ingestion time - equal to the shorter of the radionuclide's mean lifetime or 365 days.

D = decay correction term, where $D = \frac{1 + e^{-\lambda t}}{2}$; t is the shorter of the nuclide's mean lifetime in days or 365 days; λ = radionuclide decay constant in days^{-1}.

Leafy Vegetables and Produce (Tables 4 & 5)

$$C = \frac{(PAG)(10^{-6})}{(IR)(EIT)(DCF)(D)} = \mu Ci/kg$$

where: IR = daily ingestion rate (kg/day)

EIT = effective ingestion time in days (for short-term derived response levels, equivalent to the shorter of the radionuclide mean effective lifetime or 30 days; and for long-term derived response levels, equivalent to the shorter of the radionuclide mean lifetime or 365 days)

λ = radionuclide decay constant ($days^{-1}$)

$D = \frac{1 + e^{-\lambda t}}{2}$; where for short-term, t = the shorter of the radionuclide's mean effective lifetime or 30 days, and for long-term, t = the shorter of the radionuclide mean lifetime or 365 days.

Leafy Vegetables and Produce (Tables 9 & 10)

$$C_a = \frac{(PAG)(10^{-6})(2)(A)}{(IR)(EIT)(DCF)(D)} = \mu Ci/m^2$$

where: C_a = areal concentration ($\mu Ci/m^2$)

2 = agricultural productivity by unit area (kg/m^2)

A = fraction of area that is edible, assumed to be 1 for Table 9 & 10 calculations

NOTE: The agricultural productivity by unit area of 2 kg/m^2 used in these calculations is an average value. Actual values should be taken into account when they are known for a specific geographic area. Also, the fraction of the plant area that is edible may be taken into account. The areal activities in Tables 9 and 10 do not apply to root crops if the harvest is not in progress and the produce is not on the ground surface during the accidental release of radioactivity. Also, the areal activities in Tables 9 and 10 are not equivalent to the initial deposition activity on the ground or other flat surfaces. In order to estimate the initial deposition activity, the values in Tables 9 and 10 should be multiplied by a factor of 2 to account for the 0.5 retention factor for deposition on vegetation.

APPENDIX A - REFERENCES

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ANNEX 1 TO APPENDIX A

Effective Ingestion Time, Effective Decay Time, and Decay Correction Factor

The effective ingestion time (EIT) determines the length of the ingestion period which determines the total quantity of leafy vegetables or produce which is ingested. This approach provides a realistic means of determining one derived concentration level which would produce the PAG dose. The EIT is defined as the shorter of the radionuclide's mean effective lifetime (or mean lifetime) or some other arbitrary time limit (e.g., the EPA guidance suggests one year).

For food items that may be stored for some period of time before they are consumed, there meeds to be a decay correction. In order to calculate single derived response level, this decay correction needs to be determined for some average decay time. This decay time should be related to the average activity for the length of the ingestion period. Since the decay term is an exponential function, the length of decay period cannot be a simple arithmetic average based on the length of the ingestion period. The average decay time must be relative to the average activity for the duration of the ingestion period. Therefore, the effective decay time (t_x) is equal to:

$$t_x = \frac{\ln\left(\frac{1+e^{-\lambda t}}{2}\right)}{-\lambda}$$

This can be proven as follows:

let A_1 = Activity at time 0 (the begining of the ingestion period)

A_2 = Activity remaining at $t = \overline{T}_E$ or $\overline{T}$ or some upper set time limit (1 day, 5 days or 365 days, etc) which is at the end of the ingestion period.

A_3= Average activity for the ingestion period.

The time at which the average activity occurs can be determined graphically, see Figure AA-1 or the above equation can be derived from the above activity relationships as follows:

$A_1 = A_1 e^{-\lambda t_o}$; initial activity

$A_2 = A_1 e^{-\lambda t}$; activity remaining at the end of the ingestion period

$A_3 = A_1 e^{-\lambda t_x}$; average activity - activity remaining at time t_x which is equivalent to one half of the activity that has decayed during time t.

The total activity decaying during the ingestion period is equal to:

$$A_1 - A_2 \text{ or } A_1 e^{-\lambda t_o} - A_1 e^{-\lambda t} \text{ or } 1 - A_1 e^{-\lambda t}$$

Therefore, $A_3 = A_1 e^{-\lambda t_x} = A_1 - \left(\frac{A_1 - A_2}{2}\right)$ or $A_1 e^{-\lambda t_o} - \left(\frac{A_1 e^{-\lambda t_o} - A_1 e^{-\lambda t}}{2}\right)$

Solving for t_x the time at which A_3 occurs:

$$A_1 e^{-\lambda t_x} = A_1 e^{-\lambda t_o} - \left(\frac{A_1 e^{-\lambda t_o} - A_1 e^{-\lambda t}}{2}\right)$$

Simplifying by dividing both sides by A_1

$$e^{-\lambda t_x} = e^{-\lambda t_o} - \left(\frac{e^{-\lambda t_o} - e^{-\lambda t}}{2}\right)$$

at $t_o = 0$, $e^{-\lambda t_o} = 1$, therefore

$$e^{-\lambda t_x} = 1 - \left(\frac{1 - e^{-\lambda t}}{2}\right)$$

$$2\, e^{-\lambda t_x} = 2 - 1 + e^{-\lambda t}$$

$$2\, e^{-\lambda t_x} = 1 + e^{-\lambda t}$$

$$e^{-\lambda t_x} = \frac{1 + e^{-\lambda t}}{2}$$

$$\ln\left(e^{-\lambda t_x}\right) = \ln\left(\frac{1 + e^{-\lambda t}}{2}\right)$$

$$-\lambda t_x = \ln\left(\frac{1 + e^{-\lambda t}}{2}\right)$$

$$t_x = \frac{\ln\left(\frac{1 + e^{-\lambda t}}{2}\right)}{-\lambda}$$

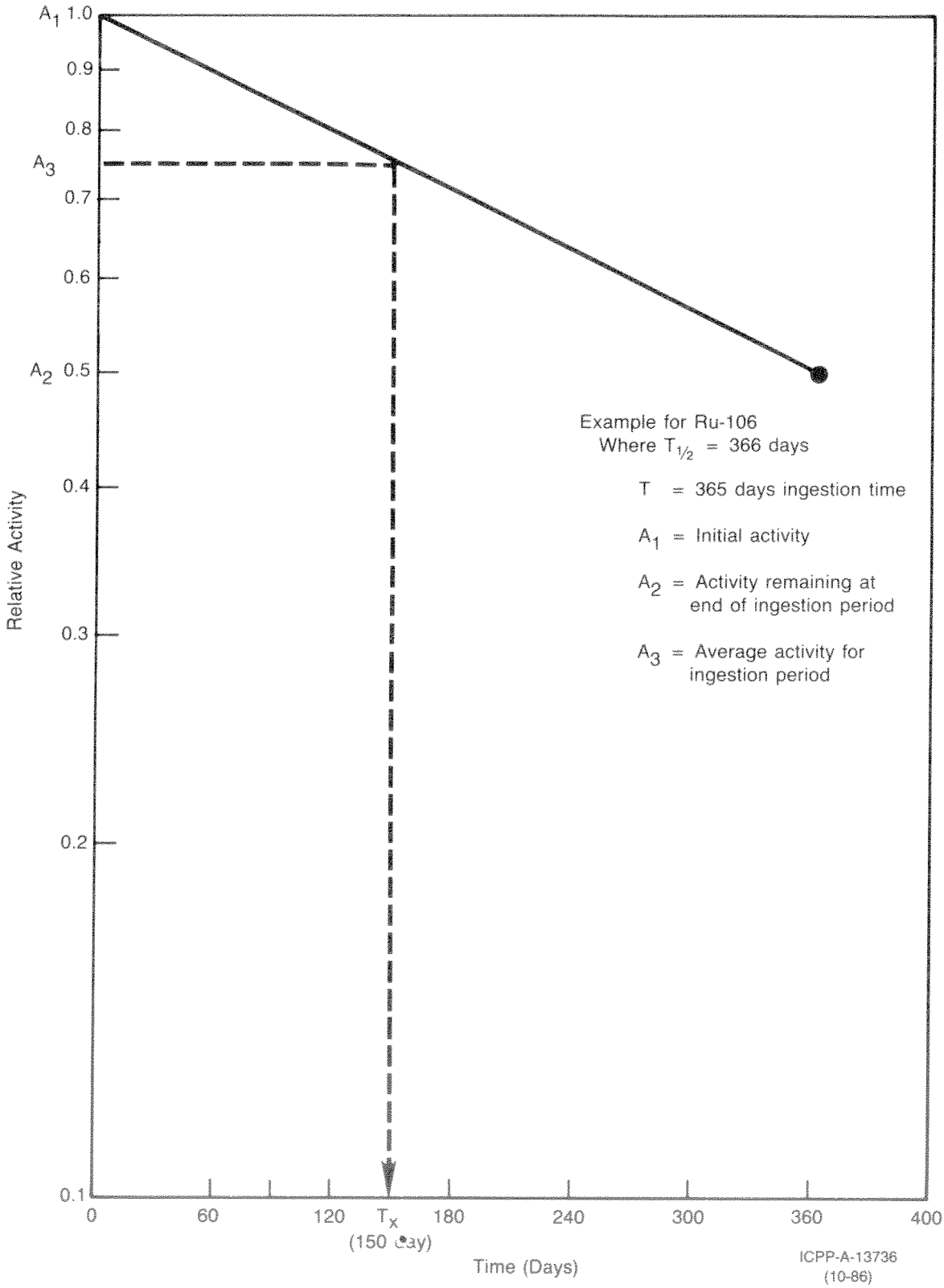


Figure AA-1. Graphical Solution For Effective Decay Time (T_X)

The effective decay correction factor (D) is the average decay that would occur during the effective ingestion period and is equal to $e^{-\lambda t_x}$.

$D = e^{\lambda t_x}$

by substitution,

$$D = e^{-\lambda\left(\frac{\ln \frac{1 + e^{-\lambda t}}{2}}{-\lambda}\right)}$$

$$D = e^{\ln\left(\frac{1 + e^{-\lambda t}}{2}\right)}$$

$$D = \frac{1 + e^{-\lambda t}}{2}$$

APPENDIX B - CALCULATED RADIONUCLIDE PLUME DEPOSITION AND RESULTING INGESTION DOSE

The Reactor Safety Study (RSS)[1] groups accident sequences into sets called release categories, which were numbered in accordance with the magnitude of the radioactive release, i.e., group 1 has the greatest release fraction, group 9 the least. The RSS designations for the two example accidents, used in this report, are shown in Table B-1. The first accident presented in Table B-1 is designated by the RSS as PWR 7 AHG-epsilon. The PWR 7 signifies the release category for a pressurized water reactor; the letters signify a specific accident sequence. The AHG-epsilon seguence 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 designates a boiling water reactor accident in which the reactor coolant boundary is ruptured but all engineered safety feature 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 calculated values in the following Tables and Tables 6 and 7 of the main text are based on integrated deposition and integrated projected dose over these time intervals.

The surface concentrations shown in Table B-2 were calculated using the plume dispersion assumptions in NRC Regulatory Guides 1.3[2] and 1.4.[3] These assumptions are general in nature and are to be used in lieu of site specific data. They were devised as conservative models for use in licensing analyses and are not intended as realistic estimates; actual concentrations almost certainly would be very different. 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 NRC Regulatory Guides 1.3 and 1.4, were calculated on the following assumptions:

0-8 hour -	Pasquill Type F, windspeed 1 meter/sec, uniform direction.
0-24 hour -	Pasquill Type F, windspeed 1 meter/sec, variable direction within a 22.5@ sector.
4-30 days -	33.3% Pasquill Type C, windspeed 3 meter/sec 33.3% Pasquill Type D, windspeed 3 meter/sec 33.3% Pasquill Type F, windspeed 2 meter/sec wind direction 33.3% frequency in a 22.5@ sector.

Radionuclide surface concentrations were calculated from plume concentrations (as described above) using plume depletion and the content of relative deposition discussed in NRC Regulatory Guide 1.111.[4] These assumptions result in upper limit values for surface concentrations.

In order to evaluate the relative consequences of exposure from radionuclide deposition on vegetation, the dose commitment via ingestion must be calculated from surface concentrations. The assumptions used in converting foodstuff surface concentrations to ingestion dose were taken from NRC Regulatory Guide 1.109.[5] Dose conversion factors and ingestion rates were combined to determine dose for all radionuclides released. These calculated doses for the maximally exposed individual are presented in Table B-3. Radionuclides not included in Table B-3 do not contribute to the ingestion dose. The dose model assumes no protective actions are taken and is therefore the dose for all time from a single contaminating event via ingestion of vegetation. The models are adequate for acute releases since they are done in time steps. The ingestion dose is assumed to be chronic since it is based on annual ingestion rates.

TABLE B-1

Description of Two Examples of
Reactor Accident Sequences

Accident	Initiating Event	ESF[a] Failure	Containment Failure
PWR 7 AGH-epislon	A - large loss of coolant accident (LOCA)	H - emergency core cooling system (ECCS) failure G - failure of containment heat removal system	epsilon - containment base mat melt through
BRW 5A	A - rupture of reactor coolant boundary		

[a]ESF - Engineered Safety Features

TABLE B-3

Calculated Foodstuff Dose for
Selected Accident Sequences

Dose to the Teenager via the Food Pathway

Accident: PWR AHG-epsilon

Nuclide	Organ[a]	300m rem	1600m (1 mi) rem	8000m rem	16000m (10 mi) rem	32000m rem	80000m (50 mi) rem
I-131	Th	6.3E+03	4.3E+02	2.0E+01	5.7E+00	1.5E+00	2.2E-01
I-132	Th	1.9E-06	1.2E-07	4.7E-09	1.0E-09	1.6E-10	5.4E-12
I-133	Th	8.9E+01	6.1E+00	2.8E-01	7.7E-02	1.9E-02	2.4E-03
I-134		Half-life too short to be of concern					
I-135	Th	2.3E-01	1.6E-02	6.8E-04	1.8E-04	3.9E-05	3.5E-06
Rb-86	Lv	6.0E-04	4.2E-05	1.9E-06	5.5E-07	1.4E-07	2.1E-08
Cs-134	Lv	3.0E+01	2.0E+00	9.5E-02	2.7E-02	7.1E-03	1.1E-03
Cs-136	Lv	2.0E-02	1.4E-03	6.5E-05	1.8E-05	4.8E-06	6.8E-07
Cs-137	Lv	1.5E+01	1.1E+00	4.9E-02	1.4E-02	3.7E-03	5.5E-04
Te-127	GI	5.9E-27	4.0E-28	1.6E-29	3.9E-30	7.4E-31	4.1E-32
Te-127m	Kd	5.8E-01	4.0E-02	1.9E-03	5.3E-04	1.4E-04	2.0E-05
Te-129		Half-life too short to be of concern					
Te-129m	Kd	7.0E-30	4.6E-31	1.9E-32	4.4E-33	7.9E-34	3.8E-35
Te-131m	GI	7.0E-09	4.8E-10	2.2E-11	5.8E-12	1.4E-12	1.5E-13
Te-132	GI	4.3E-03	3.0E-04	1.4E-05	3.8E-06	9.6E-07	1.3E-07
Sb-127	GI[b]	2.6E-04	1.8E-05	8.1E-07	2.3E-07	5.8E-08	7.7E-09
Sb-129	GI[b]	6.1E-56	4.0E-57	1.4E-58	2.8E-59	3.6E-60	6.1E-62
Sr-89	Bo	2.5E+01	1.7E+00	7.9E-02	2.2E-02	5.9E-03	8.6E-04
Sr-90	Bo	6.7E+01	4.6E+00	2.2E-01	6.1E-02	1.6E-02	2.4E-03
Sr-91	GI	1.8E-25	1.2E-26	4.8E-28	1.2E-28	2.2E-29	1.3E-30
Ba-140	GI	1.7E-01	1.2E-02	5.5E-04	1.6E-04	4.1E-05	5.8E-06
Mo-99	Kd	3.3E-05	2.3E-06	1.0E-07	2.9E-08	7.3E-09	9.4E-10
Tc-99m	GI	2.2E-41	1.5E-42	5.6E-44	1.2E-44	1.9E-45	6.1E-47
Ru-103	GI	9.4E-01	6.5E-02	3.0E-03	8.5E-04	2.2E-04	3.3E-05
Ru-105	GI	2.5E-53	1.7E-54	5.9E-56	1.2E-56	1.6E-57	2.9E-59
Ru-106	GI	8.6E+00	5.9E-01	2.8E-02	7.8E-03	2.1E-03	3.1E-04
Rh-105	GI[c]	4.6E-09	3.1E-10	1.4E-11	3.9E-12	9.4E-13	1.1E-13
Co-58	GI	8.7E-03	6.0E-04	2.8E-05	7.9E-06	2.1E-06	3.1E-07
Co-60	GI	2.3E-02	1.6E-03	7.3E-05	2.1E-05	5.4E-06	8.0E-07

TABLE B-3 (Cont'd)

Accident: PWR AHG-epsilon

Nuclide	Organ[a]	300m rem	1600m (1 mi) rem	8000m rem	16000m (10 mi) rem	32000m rem	80000m (50 mi) rem
Y-90	GI	8.9E-07	6.1E-08	2.8E-09	7.8E-10	2.0E-10	2.5E-11
Y-91	GI	1.4E+00	9.4E-02	4.4E-03	1.2E-03	3.3E-04	4.8E-05
Zr-95	GI	6.9E-01	4.7E-02	2.2E-03	6.3E-04	1.7E-04	2.4E-05
Zr-97	GI	3.1E-15	2.1E-16	9.2E-18	2.4E-18	5.2E-19	4.5E-20
Nb-95	GI	1.9E-01	1.3E-02	6.1E-04	1.7E-04	4.5E-05	6.6E-06
La-140	GI	1.8E-07	1.2E-08	5.5E-10	1.5E-10	3.7E-11	4.3E-12
Ce-141	GI	2.1E-01	1.5E-02	6.9E-04	1.9E-04	5.1E-05	7.4E-06
Ce-143	GI	4.3E-09	2.9E-10	1.3E-11	3.6E-12	8.7E-13	9.7E-14
Ce-144	GI	5.1E+00	3.5E-01	1.6E-02	4.7E-03	1.2E-03	1.8E-04
Pr-143	GI	3.4E-02	2.4E-03	1.1E-04	3.1E-05	8.1E-06	1.2E-06
Nd-147	GI	6.9E-03	4.7E-04	2.2E-05	6.2E-06	1.6E-06	2.3E-07
Np-239	GI	2.7E-05	1.8E-06	8.4E-08	2.3E-08	5.8E-09	7.3E-10
Pu-238	Bo[b]	1.9E+01	1.3E+00	6.1E-02	1.7E-02	4.6E-03	6.8E-04
Pu-239	Bo[b]	8.1E+00	5.5E-01	2.6E-02	7.3E-03	1.9E-03	2.9E-04
Pu-240	Bo[b]	8.1E+00	5.5E-01	2.6E-02	7.3E-03	1.9E-03	2.9E-04
Pu-241	Bo[b]	2.5E+01	1.7E+00	8.1E-02	2.3E-02	6.0E-03	8.9E-04
Am-241	Bo[b]	6.7E-01	4.6E-02	2.2E-03	6.1E-04	1.6E-04	2.4E-05
Cm-242	Bo[b]	8.3E-01	5.7E-02	2.7E-03	7.6E-04	2.0E-04	2.9E-05
Cm-244	Bo[b]	4.2E+00	2.9E-01	1.4E-02	3.8E-03	1.0E-03	1.5E-04

ACCIDENT: BWR 5 A

I-131	Th	3.2E-03	2.2E-04	1.0E-05	2.9E-06	7.5E-07	1.1E-07
I-132	Th	4.2E-16	2.6E-17	7.1E-19	1.0E-19	7.1E-21	1.9E-23
I-133	Th	1.5E-05	1.0E-06	4.4E-08	1.2E-08	2.7E-09	2.5E-10
I-134		Half-life too short to be of concern					
I-135	Th	3.9E-09	2.6E-10	1.0E-11	2.2E-12	3.7E-13	1.4E-14
Rb-86	Lv	6.6E-07	4.5E-08	2.1E-09	6.0E-10	1.6E-10	2.3E-11
Cs-134	Lv	1.2E-02	8.4E-04	3.9E-05	1.1E-05	2.9E-06	4.3E-07
Cs-136	Lv	3.9E-05	2.7E-06	1.2E-07	3.5E-08	9.2E-09	1.3E-09
Cs-137	Lv	6.2E-03	4.2E-04	2.0E-05	5.6E-06	1.5E-06	2.2E-07
Te-127	GI	5.4E-12	3.6E-13	1.5E-14	3.6E-15	6.8E-16	3.8E-17
Te-127m	Kd	5.5E-07	3.8E-08	1.8E-09	5.0E-10	1.3E-10	1.9E-11
Te-129		Half-life too short to be of concern					
Te-129m	Kd	1.0E-11	6.7E-13	2.7E-14	6.3E-15	1.1E-15	5.4E-17
Te-131m	GI	2.0E-08	1.4E-09	6.1E-11	1.6E-11	3.9E-12	4.2E-13
Te-132	GI	1.1E-06	7.7E-08	3.6E-09	9.9E-10	2.5E-10	3.3E-11
Sb-127	GI[b]	2.6E-08	1.8E-09	8.3E-11	2.3E-11	5.9E-12	7.9E-13
Sb-129	GI[b]	1.6E-15	1.0E-16	3.6E-18	7.3E-19	9.2E-20	1.6E-21

TABLE B-3 (Cont'd)

Accident: BWR 5 A

Nuclide	Organ[a]	300m rem	1600m (1 mi) rem	8000m rem	16000m (10 mi) rem	32000m rem	80000m (50 mi) rem
Sr-89	Bo	2.8E-06	1.9E-07	9.1E-09	2.6E-09	6.7E-10	9.9E-11
Sr-90	Bo	5.4E-06	3.7E-07	1.7E-08	4.9E-09	1.3E-09	1.9E-10
Sr-91	GI	3.5E-12	2.4E-13	9.8E-15	2.4E-15	4.5E-16	2.6E-17
Ba-140	GI	6.0E-08	4.1E-09	1.9E-10	5.4E-11	1.4E-11	2.0E-12

a Th=thyroid, Lv=liver, Kd=kidney, Bo=bone, WB=whole body, GI=gastro-intestinal tract

b Soil transfer coefficient not available, dose due to direct deposition only

c Dose conversion factors taken from WASH=1400, Append. VI

APPENDIX B - REFERENCES

1. U.S. Nuclear Regulatory Commission, Reactor Safety Study, App. V, WASH 1400/NUREG (75-014) (1975).

2. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.3, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss of Coolant Accident for Boiling Reactors," Rev. 2 (1974).

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 Reactors," Rev. 2 (1974).

4. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases for Light-Water-Cooled-Reactors," Rev. 1 (July 1977).

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

APPENDIX C - 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.

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 for 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. The resources 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, 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 ICRA;
- 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 C-1. 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.

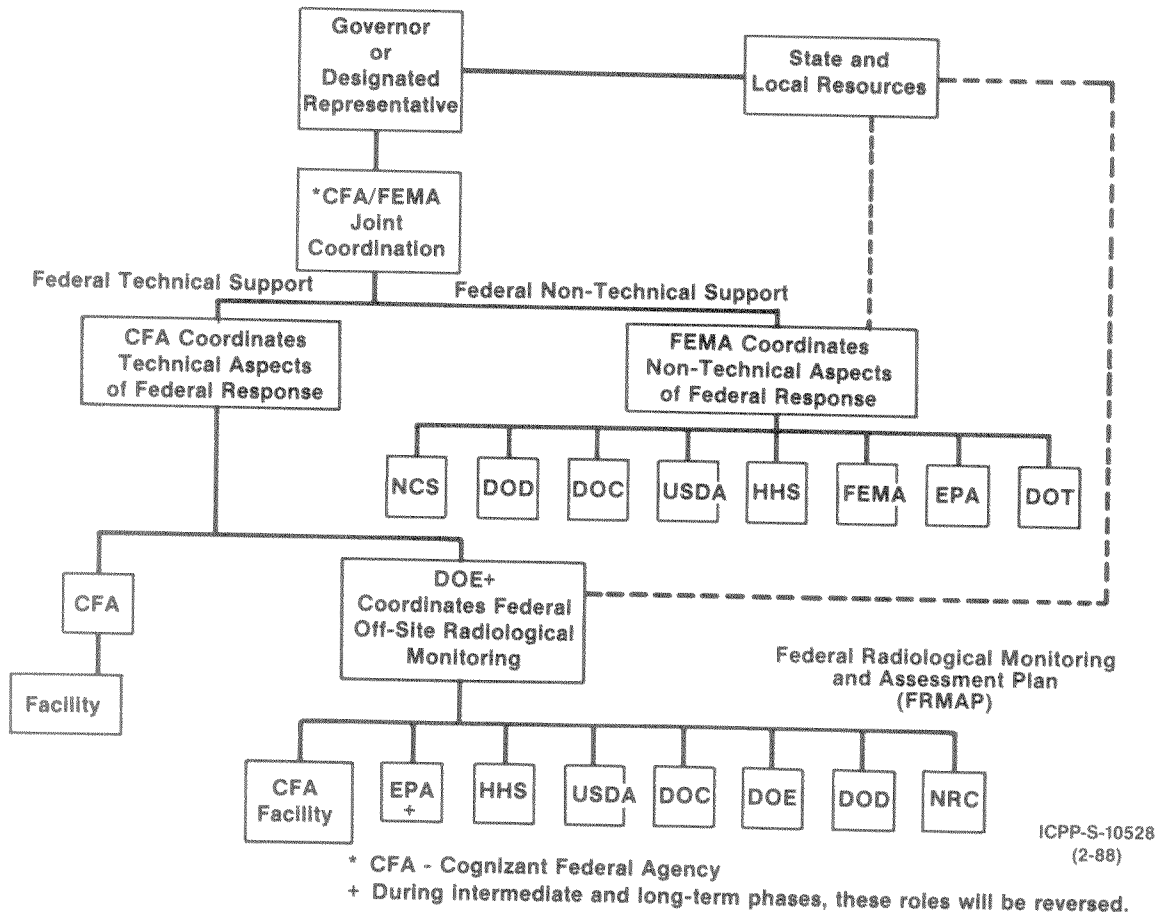


Figure C-1. Federal Response Management for a Radiological Emergency

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 a 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 employ 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.[3,4] 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. Whereas, the fixed-wing aircraft detector system has a sensitivity ranging from 1.0 to 10 $\mu Ci/m^2$ for similar gamma energies.[5] 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.[3] 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% of 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.[3] 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 contaminated foodstuffs and other non-food producing areas; 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 EOC 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. For a complete discussion of the current AMS program see Attachment 1 to this Appendix.

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 by the FRMAP organization in providing assessments to concerned State and local agencies, and AMS monitoring and sampling aircraft.

DOE is developing a program for the rapid provision of ARAC predictions so that they can be used while the full FRMAP response is being established. 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),[7] and generates printouts at the laboratory. ARAC personnel can then transmit these printouts via telephone telecopier to the user. Direct computer terminal communications is nearing completion for operational use.

Two levels of advisories are issued by ARAC, level one and level two. Level one is an early forecast of significance out to about 5 to 10 kilometers from the site that is available within 3 to 5 minutes after receipt of input data. This level one advisory could be used with a Nuclear Incident Release Notification. The onsite dose projection capability discussed above will then become the backup to ARAC.

The level two advisories are calculated by the use of validated state-of-the-art numerical modeling techniques appropriate for the magnitude of the problem, the complexity of the meteorology and topography, and the availability of input data. Level two advisories may consist of predicted concentration patterns, estimated exposure rate patterns, dose projections, and predicted ingestion pathway concentrations. These advisories are available within 30 to 40 minutes after the receipt of input data. State and local officials should use this information to determine the areas where the greatest concentration of radioiodine could potentially be deposited.

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".

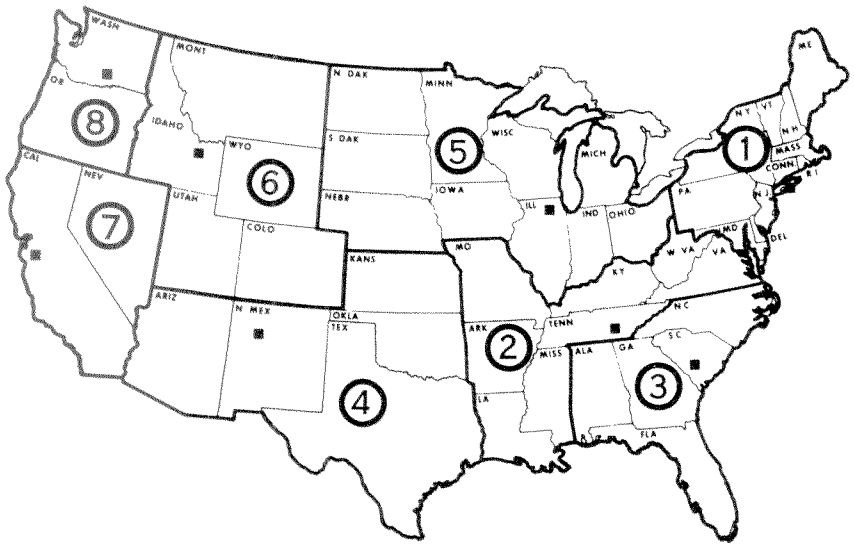
3.3 Radiological Assistance Program (RAP)

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 C-2. These regions are resource-oriented, centered about major DOE national laboratories and operations offices where the DOE resources

DEPARTMENT OF ENERGY

REGIONAL COORDINATING OFFICES FOR RADIOLOGICAL ASSISTANCE AND GEOGRAPHICAL AREAS OF RESPONSIBILITY



	REGIONAL COORDINATING OFFICE	POST OFFICE ADDRESS	TELEPHONE for ASSISTANCE
1	BROOKHAVEN AREA OFFICE	UPTON, L. I. NEW YORK 11973	(516) 282-2200
2	OAK RIDGE OPERATIONS OFFICE	P.O. BOX E OAK RIDGE, TENNESSEE 37830	(615) 576-1005 or (615) 525-7885
3	SAVANNAH RIVER OPERATIONS OFFICE	P.O. BOX A AIKEN, S.C. 29801	(803) 725-3333
4	ALBUQUERQUE OPERATIONS OFFICE	P.O. BOX 5400 ALBUQUERQUE NEW MEXICO 87115	(505) 844-4667
5	CHICAGO OPERATIONS OFFICE	9800 S. CASS AVE. ARGONNE, ILLINOIS 60439	Duty Hrs. (708) 972-4800 Off Hrs. (708) 972-5731
6	IDAHO OPERATIONS OFFICE	785 DOE PLACE IDAHO FALLS, IDAHO 83402	(208) 526-1515
7	SAN FRANCISCO OPERATIONS OFFICE	1333 BROADWAY OAKLAND, CALIFORNIA 94612	(415) 273-4237
8	RICHLAND OPERATIONS OFFICE	P.O. BOX 550 RICHLAND, WASHINGTON 99352	(509) 373-3800

REVISED: October, 1985

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

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.

4. 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 interpertation; Quality assurance procedures are managed by WEAC staff in cooperation with EPA.

5. 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 performed on milk samples as soon as they are received. Results of the analysis of iodine-131 content are available within hours.[8]

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.

6. 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 the State or local officials. These systems should be considered in addition to the normal emergency response equipment maintained by DOE laboratories.

APPENDIX C - REFERENCES

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APPENDIX C - ATTACHMENT 1

1. The Aerial Measuring Systems Program

2. Recent Advances in Airborne Radiometric Technology

3. REDAR: The Radiation and Environmental Data Aquisition and Recorder System

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The Aerial Measuring Systems Program

By J. E. Jobst*

Abstract: *EG&G, Inc., has developed for the Department of Energy (DOE) an Aerial Measuring Systems (AMS) program dedicated to environmental research at facilities of interest to DOE, the Nuclear Regulatory Commission (NRC), and other federal agencies. The AMS was originally created to measure nuclear radiation; the program scope has been broadened dramatically to include a wide variety of remote sensors: multispectral and mapping cameras, optical and infrared multispectral scanners, air-sampling systems, and meteorological sensors. The AMS maintains seven aircraft as survey platforms, both fixed-wing aircraft and helicopters. Photography, scanner imagery, and radiation data are processed in dedicated, modern laboratories and used for a broad range of environmental impact studies. A graphic overview system has been developed for effective presentation of all types of remotely sensed data obtained at a facility of interest.*

The Aerial Measuring Systems (AMS) program has been developed by the Department of Energy (DOE) and its predecessors, the Atomic Energy Commission (AEC) and the Energy Research and Development Administration (ERDA), to ensure that all energy "programs and operations are conducted in a manner that will protect the public, ensure occupational safety and health, and preserve the environment in accordance with nationally accepted norms."[1]

Much of the AMS expertise is the fruit of experience gained empirically—results from research and development in support of the Environmental Health and Safety Program of the Department of Energy. A primary goal of the Environmental Health and Safety Program is to conduct balanced health and safety research in methods to protect against potentially harmful effects of all energy systems—from raw materials to final energy use.

The AMS is a tool useful for both emergency nuclear safety problems and long-range environmental impact measurement, evaluation, and control. This article describes early systems development, the present hardware and subsystems, the data analysis process, and the special overall nonnuclear environmental measurement capability and its relation to health and safety when unsuspected nuclear contamination arises.

SYSTEM DEVELOPMENT

Aerial measurements of surface radioactivity were made in the United States as early as 1948. Their original purpose was to determine the feasibility of airborne prospecting for radioactive ore deposits.[2] The U. S. Geological Survey (USGS) and the Oak Ridge National Laboratory (ORNL) cooperated with the Division of Biology and Medicine of the AEC in these early efforts.[3] Experimental and theoretical studies led to the development of appropriate instrumentation. This equipment was used in 1950 to carry out the first systematic aerial survey of a large area (over 4100 km^2). In the mid-1950s, a series of events spurred the development of this aerial radiological measuring system by the USGS and ORNL. These events included the United Kingdom Windscale reactor accident, the release of radioactive clouds from nuclear weapon tests in Nevada, and the emergence of commercial power reactors.

The Windscale accident involved a partial core meltdown and subsequent release of radioactive gases for several days. These gases and particulates blanketed a large area surrounding the Windscale facility and severely taxed the health physicists charged with monitoring the affected areas. No airborne capability existed in England at the time to provide a rapid, large-area assessment of the problem.

The radiological measuring system developed to aid in locating uranium deposits in the western United States was temporarily called on to track several radioactive clouds released by the Weapons Test Program at the Nevada Test Site. The system proved very useful in the cloud-tracking operation, but the USGS asked the AEC to relieve them of the cloud-tracking activity. In 1959 the AEC asked EG&G, Inc., to develop a second-generation system.

The aerial monitoring system that EG&G designed[4] was primarily for theoretical and experimental studies of (1) the radiation environment, (2) detector

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response, (3) operational procedures, and (4) methods for rapid acquisition, analysis, and presentation of survey data.

The AMS, as the program is now known, became operational in November 1960; the first large-area survey was conducted in 1961. Since that time a growing remote-sensing capability has been developed and operated for the U. S. government. It now incorporates a wide range of remote-sensing instrumentation and a variety of aerial platforms, performing both routine and accident-response functions.

Several aerial programs are currently served by EG&G under the direction of DOE's Nevada Operations Office. These programs share the support of a staff of 110 full-time personnel, seven aircraft, data-acquisition systems, and analysis hardware and software.

The objectives of AMS missions concern safety and environmental assessment and include (1) accident response, (2) baseline documentation, (3) accurate definition of man-made contribution to the radiation environment at sites of interest to DOE, and (4) integrated remote-sensing capability to support DOE-related programs.[5] The AMS also provides routine radiological surveys of nuclear reactors and other licensed facilities for the Nuclear Regulatory Commission (NRC). One of the primary purposes of AMS is fast response to a major accident or natural disaster. Fixed-wing and rotary aircraft, fully equipped with remote-sensing systems, are based on both the East and West Coasts to permit rapid response. The main operational base of AMS is in Las Vegas, Nev.; a smaller permanent staff is maintained at Andrews Air Force Base in Washington, D. C. The AMS supports the Interagency Radiological Assistance Program (IRAP).

In a radiological emergency, all AMS assets, personnel, and equipment become a major element of NEST, the Nuclear Emergency Search Team. Other groups from the Los Alamos Scientific Laboratory, Lawrence Livermore Laboratory, Sandia Laboratories, and elsewhere join forces to search for and assess the radiological emergency and perform any necessary decontamination.

AMS sensor systems include large-volume gamma scintillator arrays, neutron detectors, meteorological sensors, large-format aerial mapping cameras, multispectral aerial cameras, a multichannel scanner, air-sampling equipment, and extensive ground support equipment, including dedicated computers for data processing and a sophisticated multimode communication system. When not responding to an emergency or disaster situation, AMS is routinely used to provide background hydrological, geological, ecological, and radiological baseline data on sites of interest to DOE. These include all operating nuclear power plants, radioactive waste storage facilities, and all DOE nuclear and energy development sites. Formal reports are prepared for each of the DOE and NRC surveys. These reports are useful for routine environmental impact statements and provide the basis for future detailed accident assessment, should that ever be necessary. Their preparation constantly maintains proficiency for accident response.

AERIAL SURVEY EQUIPMENT

In Las Vegas, AMS maintains four aircraft: a Convair 580-T, a Beechcraft Twin Bonanza E-50, a Hughes H-500 helicopter, and a Boeing BO-105 helicopter. A Beechcraft King Air A-100, a Hughes H-500, and a Boeing BO-105 are stationed at Andrews Air Force Base. These aircraft are shown in Fig. 1. As mission requirements change, various sensor systems are mounted aboard an appropriate aircraft. Sometimes more than one system is used on a given mission. Since the aircraft performance capabilities are fairly well-known, the special emphasis here will be placed on the sensor systems, their performance specifications, and how the data are applied to a specific problem.

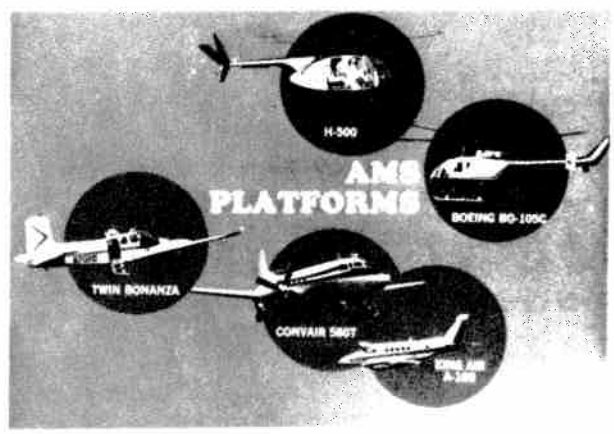

Fig. 1 Seven aircraft are maintained by EG&G as AMS aerial survey platforms. This fleet is supplemented by various military aircraft for special purposes.

Radiological Sensors

The AMS relies primarily on arrays of sodium iodide crystals to detect gamma radiation from aerial

platforms. Crystals of various sizes and arrays of various weights and configurations are assembled as required.

For relatively small areas, AMS relies heavily on a pair of detector pods, each containing ten 12.7-cm-diameter by 5.1-cm-thick sodium iodide [NaI(Tl)] detectors. These are attached to the outside of the H-500 helicopter fuselage. Even though the H-500 has a limited range (500 km), its variable speed (0 to 200 km/hr) and low altitude capability provide a very flexible platform for precision radiation surveys. Survey patterns are regularly flown at an altitude of 30 m, with a speed of 110 km/hr and a line spacing of 30 m. In a typical day of survey work, the H-500s are airborne approximately 4 hr. By operating from a support base at the site, which is easily accomplished, this system can fly over 400 km of survey line and complete a 10-km^2 site within 1 day.

Gamma counts from all 20 detectors are summed. Count rates, gamma spectral data, aircraft position information, clock time, live time, radar altitude, and meteorological data are recorded on magnetic tape for subsequent analysis. Several real-time displays keep the two-man crew abreast of survey progress.

Special importance is attached to the vertical and horizontal position of the aircraft at all times. Since the source signal drops sharply with increasing altitude, radar altimeter readings that are accurate to ±0.6 m are recorded every second. During processing, count rates are corrected for altitude variations.

Fixed reference points are established at each site by positioning a pair of transponders from a microwave ranging system (MRS). The master unit, in the helicopter, interrogates the slaves and calculates aircraft position to better than ±3 m. These data are recorded each second. A computer, also linked to the ranging system, drives a steering indicator in the cockpit. By "flying the needle," the pilot can fly programmed survey lines with great accuracy. This, in turn, assures complete coverage of the site and provides maximum assurance that even weak radioactive sources will be detected.

All data from radiological and meteorological sensors, as well as time and position information, are automatically recorded by the Radiation and Environmental Data Acquisition and Recording (REDAR) system shown in Fig. 2. REDAR is highly interactive, allowing the operator to select and display several

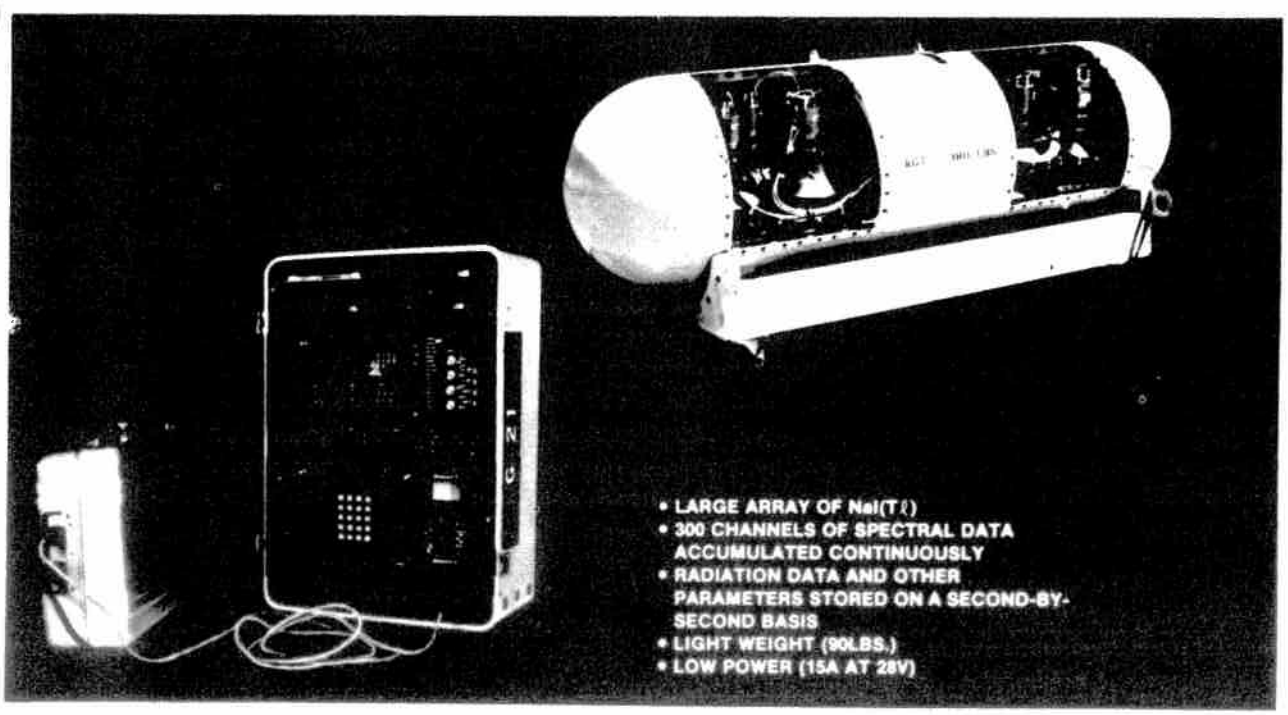

Fig. 2 The REDAR system consists of a power supply (11 kg), a processing and recording unit (33 kg), and various detector modules. The 170-kg detector pod shown at the upper right is half of the large array discussed under the heading Radiological Sensors. The processing unit handles input from many types of sensors simultaneously.

Table 1 Large-Array Conversion Factors

Isotope	Relaxation length, cm	Sample depth, cm	Detector response: nCi/m² / counts/sec	Detector response: nR/hr* / counts/sec	Detector response: fCi/g / counts/sec
^{137}Cs	5	3	0.94	3.4	9.4
^{137}Cs	5	10	0.94	3.4	5.4
^{137}Cs	15	3	1.8	3.2	7.4
^{137}Cs	15	10	1.8	3.2	6.0
^{60}Co	5	3	0.51	7.65	5.1
^{60}Co	5	10	0.51	7.65	3.0
^{60}Co	15	3	0.94	7.24	3.8
^{60}Co	15	10	0.94	7.24	3.1
^{241}Am	5	3	8.3		83.0
^{241}Am	5	10	8.3		48.0
^{241}Am	15	3	2.0		81.0
^{241}Am	15	10	2.0		65.0

*Measured at 1 m above ground.

portions of the gamma spectrum simultaneously. Spectra can be added, and background can be subtracted. Its great flexibility permits the real-time analysis required for aerial search activity. REDAR is used in all radiological surveillance, except snow surveys, for which a different system has been developed.

The sensitivity of various AMS detector systems is a complicated function of crystal volume, survey altitude, gamma-ray energy, source distribution, aircraft speed, and other variables. No point is served here by presenting all the results of elaborate experiments and computations that have been made to express AMS results accurately, in meaningful units, for all these variables. Table 1, however, shows typical response parameters for a large array of crystals (40 detectors, 12.7 by 5.1 cm) flown at an altitude of 30 m by a helicopter.

Typical values of air density, soil density, and soil composition were assumed. The gamma-ray relaxation length in the soil is a function of energy and soil composition. The last three columns convert counts per second in the gamma photopeak window to nCi/m^2 (nanocuries per square meter), to nR/hr (nanoroentgens per hour, measured at a distance of 1 m above ground), or to fCi/g (femtocuries of isotope per gram of soil). Sample depths for a ground survey must be accurately known if these aerial survey results are to be compared with ground survey results. The dramatic difference between the ^{60}Co and ^{241}Am results, for comparable conditions, is due to the large difference in their gamma-ray energies (1.17321 and 1.33248 vs. 0.0595 MeV). The H-500 system response is half of that shown in Table 1, since it uses 20 of the same type of crystals.

Most nuclear power reactors are surveyed with the A-100 King Air from an altitude of 152 m at a velocity of approximately 77 m/sec. Table 2 shows the response from 28 detectors (10.2 cm in diameter by 10.2 cm high), again assuming typical air and soil conditions.

Table 2 King Air Detector Array Conversion Factors*

Distribution, cm	^{137}Cs: CF, nR/hr / counts/sec	^{137}Cs: MDA, μR/hr	^{60}Co: CF, nR/hr / counts/sec	^{60}Co: MDA, μR/hr
Surface	41.6	3.2	73.2	4.6
0.1	37.4	2.9	66.5	4.2
1.0	28.8	2.2	50.3	3.2
2.0	26.9	2.1	45.5	2.9
3.0	26.0	2.0	44.3	2.8
10.0	25.1	2.0	40.2	2.5
Volume	25.1	2.0	38.9	2.5

*CF, conversion factor (nanoroentgens per hour per count per second).

MDA, minimum detectable activity, in units of microroentgens per hour at the 99% confidence level.

Surface, infinite planar source with no vertical distribution.

Volume, source is uniformly distributed from the surface to infinity.

Note: Other distributions are expressed in terms of relaxation depths for an exponentially distributed source. The indicated exposure rates are to be measured at a distance 1 m above the soil surface.

The minimum detectable activity (MDA) for this system was calculated by measuring the statistical variations in signal strength after background had been stripped away from data obtained over typical survey sites containing variable concentrations of natural isotopes producing exposure rates of 4 to 6 μR/hr. The MDA (the minimum signal that would indicate a source of interest) was set at +3 standard deviations for terrain devoid of the isotopes being sought. Hence less than 1% of strictly background data should yield erroneous ^{60}Co or ^{137}Cs indications. Because of statistical fluctuations superimposed on the signal plus background, a source corresponding to the minimum signal would be detected 50% of the time.

In addition to the gamma-ray detector systems, AMS has also developed sensitive neutron detector arrays for aerial deployment. The detector is a 7-cm-diameter by 188 cm-long tube filled with ^{3}He under high pressure and surrounded by a polyethylene moderator. An array of 24 tubes with appropriate power supply and counting electronics can be quickly mounted on the H-500 or other helicopter. These arrays are useful for neutron sources, some of which emit gamma rays of such low intensity that they are nearly undetectable with sensitive NaI detector arrays.

Camera Systems

AMS employs several camera systems, primarily on fixed-wing aircraft (Twin Bonanza, Convair 580-T, and King Air A-100). Occasionally, military aircraft are used as aerial platforms. One system consists of four Hasselblad 500 EL/M cameras mounted closely and aligned to yield identical fields of view. Synchronous framing provides multispectral photography on 70-mm film; 10 to 80% overlap between frames provides full coverage. By proper selection of film sensitivity and optical filter combinations, this system can be used to cover any four wavelength bands in the spectrum from visible to near-infrared (400 to 900 nm). Typical choices are shown in Table 3.

Imagery obtained with this system is of very high quality and extremely useful when comparative information regarding the spectral properties of surface objects is required. Either 80- or 50-mm lenses are used. With the latter, each frame covers 18 by 18 km, centered on the nuclear reactor or other site of interest.

The Hasselblad multispectral system is routinely used for documentary photographic studies near nuclear power plants. When provided with a photographic data base recorded at the time of plant startup, a photo interpreter can detect changes in vegetation type or growth stress in existing vegetation by comparing these with similar imagery obtained after the plant has been in operation for some time. Such changes may be related to power-plant operation. Changing land use and demographic studies are made possible because complete coverage of each power plant is provided every few years by AMS.

Table 3 Multispectral-Band Photography (Hasselblad)

Film type	Filter	Band, nm
Kodak Aerocolor Negative Film 2445	Wratten 2A (haze)	400 700
Kodak Aerochrome Infrared Film 2443	Wratten 12 (yellow)	500 900
Kodak Plus-X Aerographic Film 2402	Wratten 25	600 700
Kodak Infrared Aerographic Film 2424	Wratten 89B	700 900

The AMS program also depends on large-format aerial mapping cameras for many projects. Large color photographs of sites are frequently used as base maps for radiological surveys. The Convair is equipped with twin Wild-Heerbrugg RC-10 aerial mapping cameras with a periscope viewfinder and camera control system. The King Air accepts just one such camera, as shown in Fig. 3. The RC-10 produces 23- by 23-cm vertical aerial photographs of mapping quality. The system is normally operated at altitudes between 3 and 9 km, with normal aerial color film (Kodak Aerocolor Negative Film 2445), at 60% forward overlap to provide imagery suitable for stereo viewing. Such photographs are used wherever geometrical accuracy, high resolution, and normal color presentation are desirable. Other films, such as Infrared Color Type 2443, are also used. Two lenses are used: a 153-mm focal length with a resolving power of 60.1 cycles/mm and an 89-mm lens with a resolving power of 42.2 cycles/mm. The former has a field of view 1.5 times the aircraft altitude: at 3 km a single frame covers 4.5 by 4.5 km.

Each site for a radiological survey is usually photographed with the RC-10 a few days before the survey starts. Prints are used immediately for survey planning and again as a base map for radiation isopleth contours in the survey report.

Multispectral Scanner

The Convair is also equipped with a Daedalus multispectral scanner system. The spatial resolution is

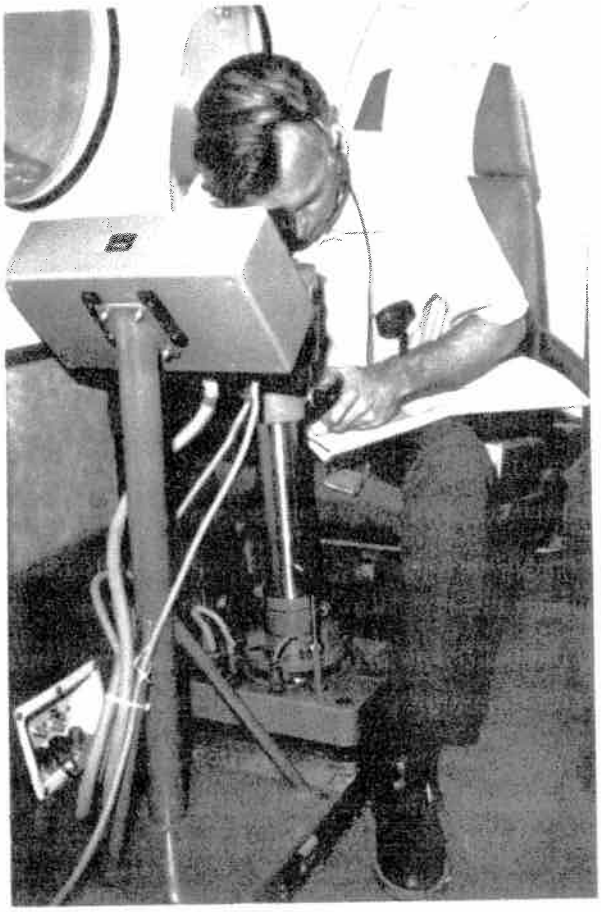

Fig. 3 The Wild-Heerbrugg RC-10 is shown here in the King Air A-100. The operator guides the pilot directly over target. The control system automatically adjusts the framing rate to produce a preset overlap between frames.

not as good as either camera system, but spectral selection is better and covers a much greater wavelength range. Direct measurements of thermal emission can be made in the infrared band as well as in the visible and ultraviolet bands. There are 10 optical channels, completely covering the range 0.38 to 1.10 μm. Two thermal channels cover the 4.5 to 5.5 and 8.5 to 11 μm bands. In operation, the Daedalus scanner views a ground scene in up to 11 bands simultaneously (10 optical plus 1 of the 2 thermal) measuring reflected and emitted radiation in the ultraviolet, visible, and infrared. Line-by-line imagery is constructed, similar to a television raster, to provide a photograph-like image of the overflown area. The lines are roll-corrected to remedy distortion caused by rotation of the aircraft about the longitudinal axis of the fuselage. Other system specifications are shown in Table 4.

Table 4 Daedalus Multispectral Scanner Parameters

Parameter	Symbol	Specification
Instantaneous field-of-view on the ground	IFOV	2.5 mradians
Noise equivalent temperature difference	NEΔT	≤0.1°K
Noise equivalent reflectance difference	NEΔρ	1–2% (ultraviolet); <1% (visible and reflecting infrared)
Wavelength coverage		
optical (10 channels)		0.38 to 1.1 μm
thermal (2 channels)		4.5–5.5, 8.5–11 μm
Roll correction		±15°

Multispectral scanner imagery neither supports nor complements radiological survey data. Its imagery is a dynamic branch of remote-sensing technology which makes a distinct contribution to AMS capabilities. Personnel, aircraft, and other support equipment are shared among AMS groups.

Other Systems

The Twin Bonanza and King Air are equipped with gas- and particulate-sampling systems to permit real-time sampling of airborne contaminants. The King Air system permits isokinetic sampling with 13-cm-diameter filters at 24 liters/sec. For high-efficiency gamma spectroscopy, the filters are analyzed on board with a sodium iodide detector. Filters are counted immediately after exposure and at carefully selected intervals thereafter to separate and identify the short- and long-lived isotopic contaminants. For high resolution, GeLi or high-purity Ge detectors are employed. These systems include various ports for whole gas sampling or the addition of other instruments, such as a nephelometer or a multistage Lundgren cascade impactor. Particles are collected on thin mylar films which can be analyzed by alpha-particle-induced X-ray fluorescence or by inductively coupled plasma optical spectroscopy.

AMS fixed-wing aircraft are equipped with various meteorological sensors for special applications. Absolute barometric pressure, outside air temperature, dew point, wind speed, wind direction, turbulence, and other parameters are often required background data for remote-sensing missions. The REDAR system records these along with radar altitude, exact aircraft position, and clock time to provide complete documentation for special missions as they occur.

DATA ANALYSIS

Computer Processing

Data from radiation surveys are initially processed on site within a NOVA 840 computer, which has a 32,000-word core memory and an additional 1.2×10^6 word disk memory. Accessories include two data tape drives, two plotters, a cathode-ray tube (CRT) display, and a hard copier. The system, shown schematically in Fig. 4, is called REDAC (Radiation and Environmental Data Analyzer and Computer).

Many software routines are available. Gamma spectral windows can be selected from any portion of the spectrum between 50 keV and 3 MeV. Weighted combinations of such windows can be summed or subtracted; by proper selection of such windows, it is possible to extract photopeak count rates for radioisotopes deposited on the terrain by human activity. The count rates are converted to isotope concentrations or exposure rates and plotted as a function of position. The resulting isopleth contour map is superposed on a recent color photograph of the site. A typical radiation contour map is shown in Fig. 5.

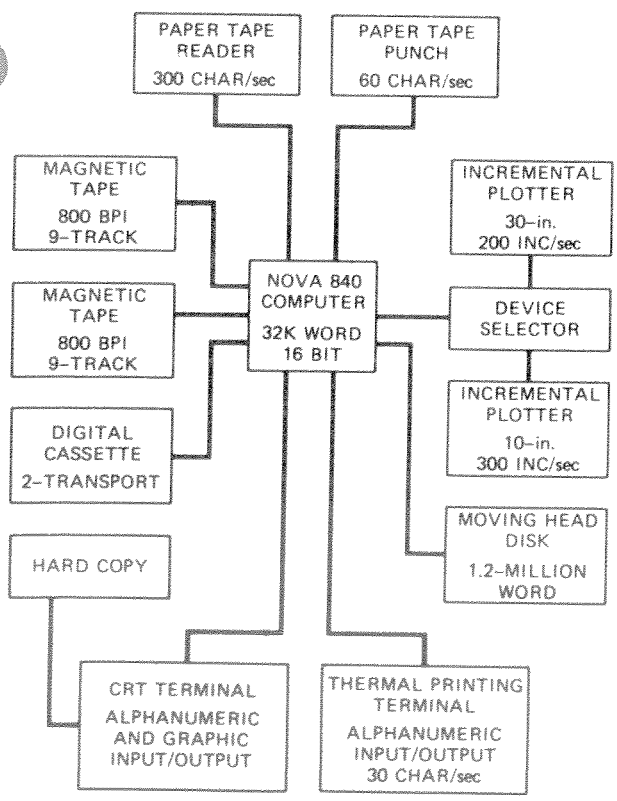

Fig. 4 A block diagram of the REDAC (Radiation and Environmental Data Analyzer and Computer) system.

In most cases, preliminary copies of a radiation isopleth map are presented to the facility manager immediately after the survey and before the crew leaves the site. Two mobile computer laboratories have been built into 5-ton step vans, as shown in Fig. 6. One mobile laboratory accompanies the aircraft to each survey site. Even greater speed and adaptability is being pursued; a third computer laboratory was recently built into an airline cargo container of the type normally used by wide-bodied jets. The AMS can now airlift a fully operational magnetic tape data-processing laboratory to any major city in the world just as conveniently as passenger luggage.

Photographic Processing

AMS maintains a complete photo processing laboratory equipped with modern, high-speed processing and printing equipment. A scientific photographer directs a full-time staff of 15 photographers and photo technicians. In addition to the Wild-Heerbrugg RC-10 and Hasselblad cameras mentioned previously, the photo staff uses many 35-mm cameras for documentary work, such as the Olympus OM-1 and Nikon F2AS. Hand-held Hasselblad cameras are also used frequently for documentary work.

Nearly all photo processing, color as well as black and white, is performed in dedicated AMS support facilities. A wide variety of development processes is used for rolls 60 m long or more. Contact prints and enlargements up to 1.3 by 3 m are routinely provided. Other services include slide and viewgraph production and prints from slides (Cibachrome or internegative). Nine graphic artists work with the photo laboratory and the scientific staff to produce radiation isopleth maps, reports, and data displays.

Image Processing

AMS has recently acquired [from ESL, Inc. (formerly Electromagnetic Systems Laboratories, Inc.) of Sunnyvale, Calif.] a state-of-the-art, interactive data-processing system, designed and dedicated to the processing and analysis of image-related data. All types of imagery can be analyzed once it has been converted to digital form. The system is presently dedicated full time to the processing of scanner imagery.

The system hardware consists of an HP-3000II minicomputer, 350 megabytes of disk storage, a Comtal Vision One display and microprocessor unit,

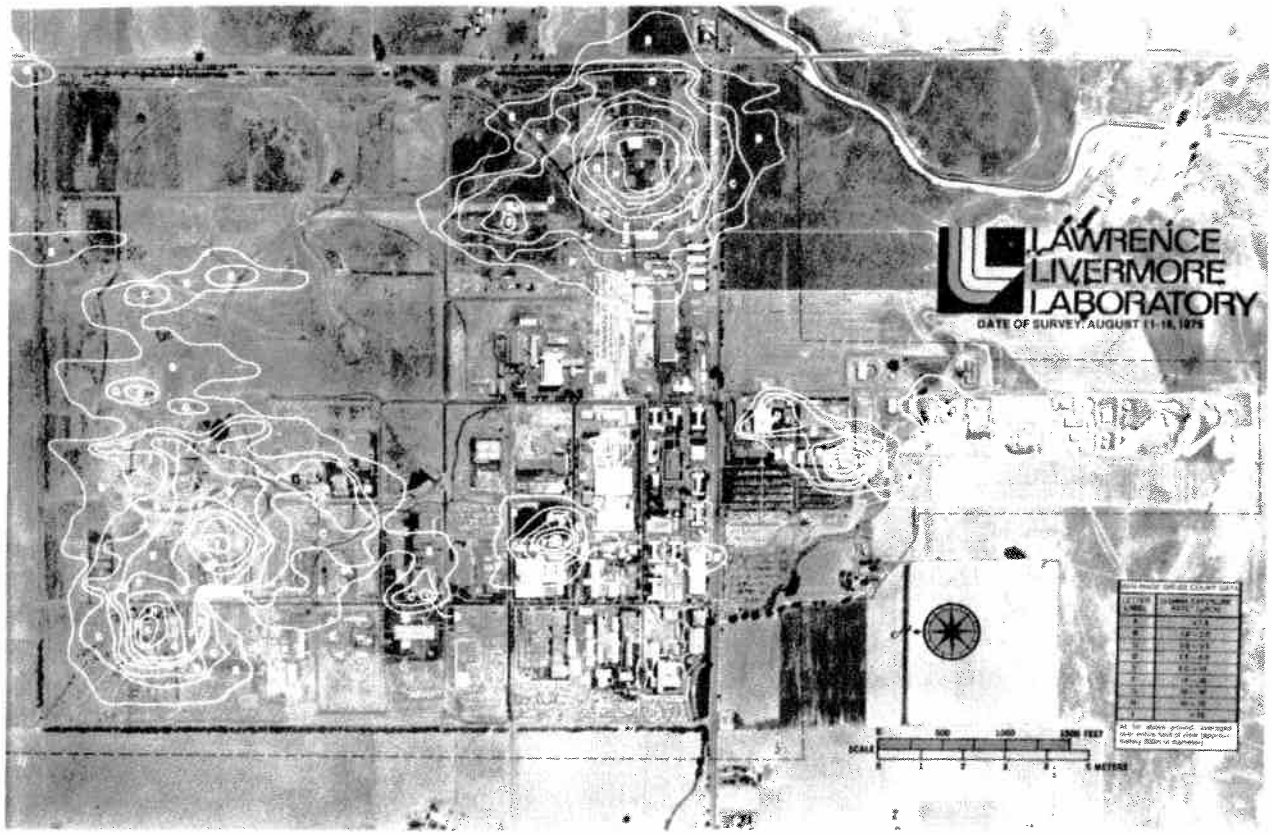

Fig. 5 This typical gamma-radiation isopleth was obtained over Lawrence Livermore Laboratory. Forty NaI(Tl) detectors (12.7 cm in diameter by 5.1 cm thick) were flown at an altitude of 45 m. The survey work was completed on Aug. 13, 1975.

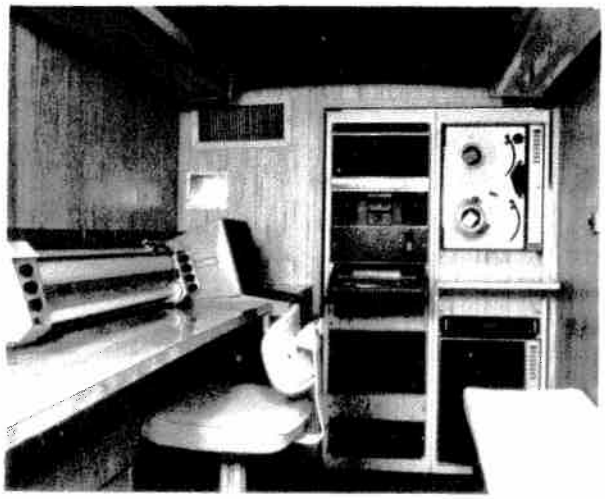

Fig. 6 The REDAC system processes magnetic tapes recorded by REDAR. Gamma spectra may be obtained immediately after the aircraft returns from a flight. Sophisticated software permits preparation of radiation isopleth contours in the field.

and a number of input–output devices. The accompanying software was specifically developed to take advantage of the characteristics of the hardware. Over 100 specially designed algorithms and enhancement functions are accessible to process and analyze the imagery. Included are transforms, maximum-likelihood classification, statistical analysis, ratioing, and many more capabilities ideally suited to the analysis and interpretation of a broad range of remotely sensed data.

APPLICATION OF NUCLEAR SURVEYS

The primary objectives of AMS radiological surveys were stated earlier, viz., to provide baseline documentation, to define any man-made contributions to the natural radiation environment, and to assess a radiological accident or disaster. Many AMS surveys are completed before a new reactor or nuclear facility begins operation.

Reactor surveys, before or during operations, are typically flown with a fixed-wing aircraft, such as the King Air, at an altitude of 150 m and a speed of 80 m/sec. A 46- by 46-km square, centered on the facility, is flown with 0.93-km (0.5 nautical mile) spacing. Five flights of 3 to 4 hr each are required to accumulate the survey data. Generally, such surveys are completed in 1 week because of presurvey calibration work and MRS setup and postsurvey data analysis. Preliminary analysis is done with the REDAC system (Fig. 6) on site. The facility operators are invited to review the results as they are processed in the field. If anomalies are observed, gamma spectra at points of interest can be examined and isotopes can be identified. Much of the data required for remedial action can be provided immediately at the site. A final report is prepared after complete analysis, evaluation, and review by the AMS senior staff. Depending on the urgency and the priorities established by NRC, DOE, or other agencies that commission AMS surveys, the report is published within a few weeks or as long as a year or more after the survey.

Large facilities, such as the Hanford Reservation or the Idaho National Engineering Laboratory, may require survey crews, aircraft, and the computer processing laboratory to be on site for as long as 5 weeks. Such reports are generally quite complex and require considerably more time to prepare.

As indicated in an earlier section, the REDAC system can be programmed to select the photopeak of a given isotope. Background and the Compton tails of other prominent isotopes can be stripped from the detector response; the resulting isopleth map for a specific isotope is invaluable for assessing the environmental impact of multiple sources at a single facility. Considerable interaction with facility operators is required in some cases, so that the aerial survey flight pattern will complement the radiation monitoring and soil sample program established at the facility.

For large facilities where detailed, low-altitude data are required, 40 NaI detectors are usually flown on a large helicopter such as the BO-105 or on military helicopters such as the UH-1N or SH-3. For smaller areas the H-500 has proved to be an excellent vehicle, as indicated under the heading Radiological Sensors.

One very interesting application of the radiation survey techniques should be mentioned. Since 1969, AMS has cooperated with the National Weather Service in a research and development program. Airborne radiological measurements are used to determine the attenuation of terrestrial gamma rays caused by snow accumulated on the ground; these data can be used to calculate the water equivalent of the snow cover. The Twin Bonanza is flown over carefully identified survey lines before and after the snow has accumulated. Background counts due to (1) radon gas in the air, (2) cosmic rays, and (3) detector and aircraft sources are subtracted in each case. The difference in the net count rates reflects the attenuation by the snow. Calibration against traditional methods has demonstrated that this system can determine the water equivalence of snow to an accuracy of ±1 cm. This technique can be the heart of an important flood safety alert in heavy snow years.

The AMS has frequently been called on to locate lost radioactive materials. In 1968, a 330-mCi ^{60}Co source was lost in interstate shipment between Salt Lake City and Kansas City.[6] An AMS aircraft was dispatched to look for the source along a 1930-km stretch of highway. In 2 days the source was recovered. A more difficult search occurred in 1970 when a U. S. Air Force Athena missile, with an 800-mCi ^{57}Co source aboard, accidently strayed 650 km into Mexico.[7] Radar tracking provided a 5- by 15-km footprint for the target area. Over 50 military personnel had combed the area for 3 weeks when AMS was requested to support the search. With a single 2½-hr search, the source was located.

Routine aerial surveys of the Nuclear Fuel Service reprocessing facility at West Valley, N.Y., triggered extensive supplementary effort on the ground.[8] Increasing levels of off-site radionuclide deposition were discovered. Survey data showed, for example, ^{137}Cs buildup of as much as 30% per year at locations as much as 2 to 8 km off site in the plant watershed.

Over the years, aerial surveys of all the major DOE nuclear facilities and operating nuclear power plants have repeatedly identified potential problems that the site personnel had missed through existing monitoring programs. Those surveyed include such highly controlled areas as the Savannah River Plant,[9] Hanford Reservation,[10] Oak Ridge facilities,[11] Idaho National Engineering Laboratory,[12] Nevada Test Site,[13] and Rocky Flats Plant.[14]

The most dramatic application of AMS resources occurs when a radiological emergency requires deployment of NEST. This occurred most recently in the early months of 1978 when NEST was sent to the Northwest Territories of Canada. The AMS and groups from other agencies assisted the Canadian Combined Forces in the location and recovery of hundreds of fragments of Cosmos 954, a nuclear-powered Russian satellite which reentered the atmosphere and disintegrated over Canada on Jan. 24, 1978 (Ref. 15).

APPLICATIONS OF PHOTO-OPTICAL REMOTE-SENSING CAPABILITIES

The photo-optical remote-sensing capabilities of the AMS are a more recent development, providing a comprehensive site survey to those responsible for assessing and planning health protection and safety at specialized sites.

Aerial photography with precisely engineered modern cameras, such as the Wild-Heerbrugg RC-10, has proved to be invaluable, especially for radiological surveys. For many recent survey sites, the available USGS maps were inadequate because of dramatic changes in land use. For some areas the only maps available are 50 to 75 years old. When AMS surveyed the Idaho National Engineering Laboratory in 1974, most of the site had never been mapped by the USGS.

In September 1978, AMS completed aerial photography of the Northern Marshall Islands in the mid-Pacific. Included were perhaps 350 to 400 islands, most of them in atolls such as Bikini and its neighbors which may have been contaminated by bomb testing in the forties and fifties. The most recent marine charts of these areas were prepared during World War II. Some of the islands have disappeared and others have drastically changed because of natural wind and wave action. With these new aerial photographs as base maps, AMS conducted a 3-month radiological survey of the entire Northern Marshall Islands at 30-m altitude using the large detector array discussed under the heading Radiological Sensors.

For nearly all radiation surveys, AMS obtains aerial photographs, at several altitudes, of each site a few days before the survey team arrives. Prints are rectified in the AMS photo laboratory, if possible, by matching the negative with maps prepared with traditional civil survey techniques. These prints are used by the project scientist to lay out all survey lines. Often the assistance of site personnel is sought to ensure complete coverage. This planning map is used in the aircraft so that correct flight line numbers can be assigned to "mag-tape" records in the mission log. Finally, rectified prints are used as a base map in preparing the report: radiation isopleth contours are drawn directly on the print, as shown in Fig. 5. Data interpretation is vastly improved by the marriage of these two remote-sensing disciplines.

The AMS personnel have also found that multispectral photography and scanner imagery provide a wealth of complementary data which often reveal unforeseen health and safety risks. These sensors provide an important contribution to the following study areas:

Ecological Systems
- Detection of the effects of drift from cooling towers, ponds, etc.
- Detection of the effects of spills.
- Biomass inventory.
- Habitat mapping.
- Detection of stress effects on plants.
- Population census of large animals.

Water Quality
- Measurement of thermal plumes in the water system.
- Mapping of changes in size and location of wet areas.
- Detection of leakage effects from production and reinjection pipes.
- Detection of effects from water-table changes.
- Mapping surface spills.

Subsidence and Seismicity
- Detection and mapping of changes in shorelines.
- Detection of effects of drainage tile damage.
- Detection of the effects of changed hydrology.
- Mapping the location of fault escarpments, ancient shorelines, and stream beds.

Air Quality
- Measurement of vertical and horizontal profiles of particulates and gases, such as O_3, NO_X, and SO_X.

Overt Health Effects
- Detection of toxic plumes or other effluent streams by sampling, photography, or use of the scanner.

Socioeconomic Factors
- Determination of full land-use relations.
- Measurement of population distribution.
- Cataloging of new construction.

Integrated Assessment
- Baseline documentation.
- Information transfer.

Photo-optical survey capability has been steadily improved over the years. The AMS conducts surveys of DOE facilities to measure any effects which might have an impact on the surrounding environment.

The Daedalus scanner is useful for characterizing the total land mass according to basic land-use criteria. The first AMS application of this system was at the Idaho National Engineering Laboratory where

thermal-emission data were recorded to quantitatively reveal the heat loss from laboratory facilities. These data were then used to remedy unnecessary heat loss.

A scanner has also been used over the Salton Sea area of Southern California, as part of the Imperial Valley Environmental Project.[16] It has been proposed that the vast geothermal water resources there be tapped for commercial generation of electricity. The scanner was flown to determine the long-term and short-term environmental effects of heat and salt on the ecology of the area, which is dominated now by heavy agricultural usage. Multispectral photography, performed in conjunction with the scanner imagery, showed that land surrounding a new geothermal test well suffered crop damage shortly after operations commenced. One farmer was already preparing litigation for damages. The government promptly agreed to settle out of court because of the AMS data.

During another mission, scanner data near the Rocky Flats Plant revealed potential leaks and seepage from settling ponds.[17]

The AMS has also completed several multispectral scanning missions over DOE's Laramie Energy Research Center pilot projects in Wyoming, Colorado, and Utah. Coal gasification and extraction of oil from shale are test processes at these sites. Scanner data are used to monitor the effects of conversion processes. The results will be an important part of the environmental impact statements required by both state and federal governments.

Since the continued strength and vigor of the energy development programs in the United States require prompt, intelligent application of environmental controls, the future of the AMS program appears certain. New energy sources have been tapped in major programs in the past few years, and no source of energy is free, i.e., free of potentially serious environmental impact. The AMS has broadened its scope and its technology to meet our burgeoning demands for energy.

However, the wealth of data provided by AMS remote-sensing systems must be used effectively. For the past 2 years, AMS has been developing a graphic overview system for all DOE facilities. The presentation format is uniform to facilitate intercomparison. For each facility, detailed aerial photographs of the site are used as base maps. All environmental data are presented at the same scale on transparent overlays. Hence the viewer can quickly observe many interactive factors such as prevailing winds, watershed drainage, and waste burial sites. Subsequent survey results are plotted to the same scale so that, by overlapping transparencies, the viewer can graphically observe the trend of changes between surveys.

This graphic overview system can accommodate all the requirements of the U. S. Environmental Protection Agency Environmental Impact Statement. For this purpose the environmental overlays are supplemented by transparencies showing population, land use, demographic data, and even social information. The overview method thus provides DOE management with an effective tool for highlighting major environmental problem areas. It gives focus to the effort required to correct the deficiencies in any control program.

CONCLUSION

The AMS program is a multipurpose nuclear safety and environmental monitoring resource. It provides aerial photography, multispectral scanning, air sampling, radiation measurements, and other environmental data for licensed and government facilities. The AMS provides routine professional environmental monitoring and many of the imperative requirements for response to a nuclear threat or emergency. Most recently, in Operation Morning Light (a joint effort by the United States and Canada to recover the Russian nuclear satellite Cosmos 954), AMS assisted the nuclear community in its responsibility to protect the health and safety of threatened populations. Continuous research is conducted in the detection and analysis of gamma and neutron signatures; hence AMS is making a strong contribution to nuclear safety in the United States.

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EG&G
ENERGY MEASUREMENTS

RSL-8403
FEBRUARY 1984

RECENT ADVANCES IN AIRBORNE RADIOMETRIC TECHNOLOGY

by
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Presented at the
Symposium on Remote Sensing Technology
In Support of the
United States Department of Energy
23 - 25 February 1983

The DOE Remote Sensing Laboratory
Operated for the Department of Energy by
EG&G Energy Measurements, Inc.
Las Vegas, Nevada

NOTICE

This work was performed by EG&G/EM for the United States Department of Energy under Contract Number DE-AC08-83NV10282.

RECENT ADVANCES IN AIRBORNE RADIOMETRIC TECHNOLOGY

Since the inception of aerial survey work in the early 1960's, the DOE Remote Sensing Laboratory has made dramatic innovations in airborne radiometric technology. The changes have been evolutionary, forced by political and social pressure, and accelerated by dynamic improvements in data acquisition hardware and modern computational capability.

The Laboratory has witnessed at least four major changes in operational philosophy. I would like to review these changes, then discuss the equipment changes which accompanied them.

The first significant change affected the survey method. Several years ago a standard background survey, for a nuclear reactor, was performed by a fixed-wing aircraft at a speed of 120 knots. The aircraft altitude was 500 feet; the lines were spaced 1 mile or 1/2 mile apart; and the survey pattern was a square, 25 miles on a side. The objective was to repeat this pattern every few years, plot the gamma gross count, and monitor these gamma maps for possible changes. It quickly became apparent that appreciable changes in gross count could appear which were unrelated to reactor operations. Differences in soil moisture, in radon concentration, and in land use could easily produce far greater impact on the average terrestrial background than ordinary fallout from reactor operations.

An initial reactor survey is now done at a 300-foot altitude, with 500-foot line spacings; the survey pattern is a 10 × 10-mile square. Repeat surveys are flown at an altitude of 150 feet, with 250-foot line spacings; the pattern is 5 × 5 miles square. The initial survey and all subsequent surveys are done with a helicopter flying at 60 knots. Equipment used in a typical survey is shown in Figure 1.

For modern background surveys the gamma ray spectra are very carefully examined for anomalies. Because the lines are flown slowly, at low altitude, with tight line spacing, the sensitive detectors provide excellent counting statistics. Localized concentrations of isotopes—such as an outcropping of uranium ore or a concentration of worldwide ^{137}Cs resulting from local precipitation patterns—can be readily detected. Such anomalies would have been difficult to detect using the fixed-wing survey method. With modern techniques and good counting statistics, such anomalies can be readily identified. Hence the new method is far more sensitive to anomalies which could be produced by a nuclear plant.

The second change in operational philosophy is the strong emphasis now placed on accurate, detailed analysis and interpretation of radiation data. Helicopter operation at low speed and altitude is extremely reliable; the exact position of the aircraft, for every gamma spectrum it obtains, can be measured with a precision of a few feet. The REDAR IV data acquisition system records vast amounts of gamma environmental data with great accuracy, even at high data rates.

Laboratory operations have expanded dramatically. Now there are several dedicated computers, a well-developed software library, and a staff of professional computer specialists to analyze the gamma data. An extremely well-equipped photographic laboratory, computerized word processors, and a highly skilled graphic arts department now contribute to prompt, professional survey reports. The objective of program management over the past years has been to improve the technical resources and equipment of the Laboratory so that the data analyst has the facilities and time to properly analyze each survey. At the same time, the Laboratory has placed strong emphasis on coordination between the survey scientist and knowledgeable personnel at the site—before, during, and after the survey. Health physicists and environmental monitoring personnel at the survey site are contacted well in advance. They guide survey planning and are kept informed of results as the survey progresses. Frequently they review the final report and assist in data interpretation. Better Laboratory resources and careful interaction with the site personnel have resulted in a significant improvement in the technical validity of reports the Laboratory generates.

The third major change is that the Laboratory now dedicates a great portion of its time and assets to locating point radiation sources rather than dispersed ones. This change was accelerated in 1974 when the Laboratory became part of the Nuclear Emergency Search Team (NEST).

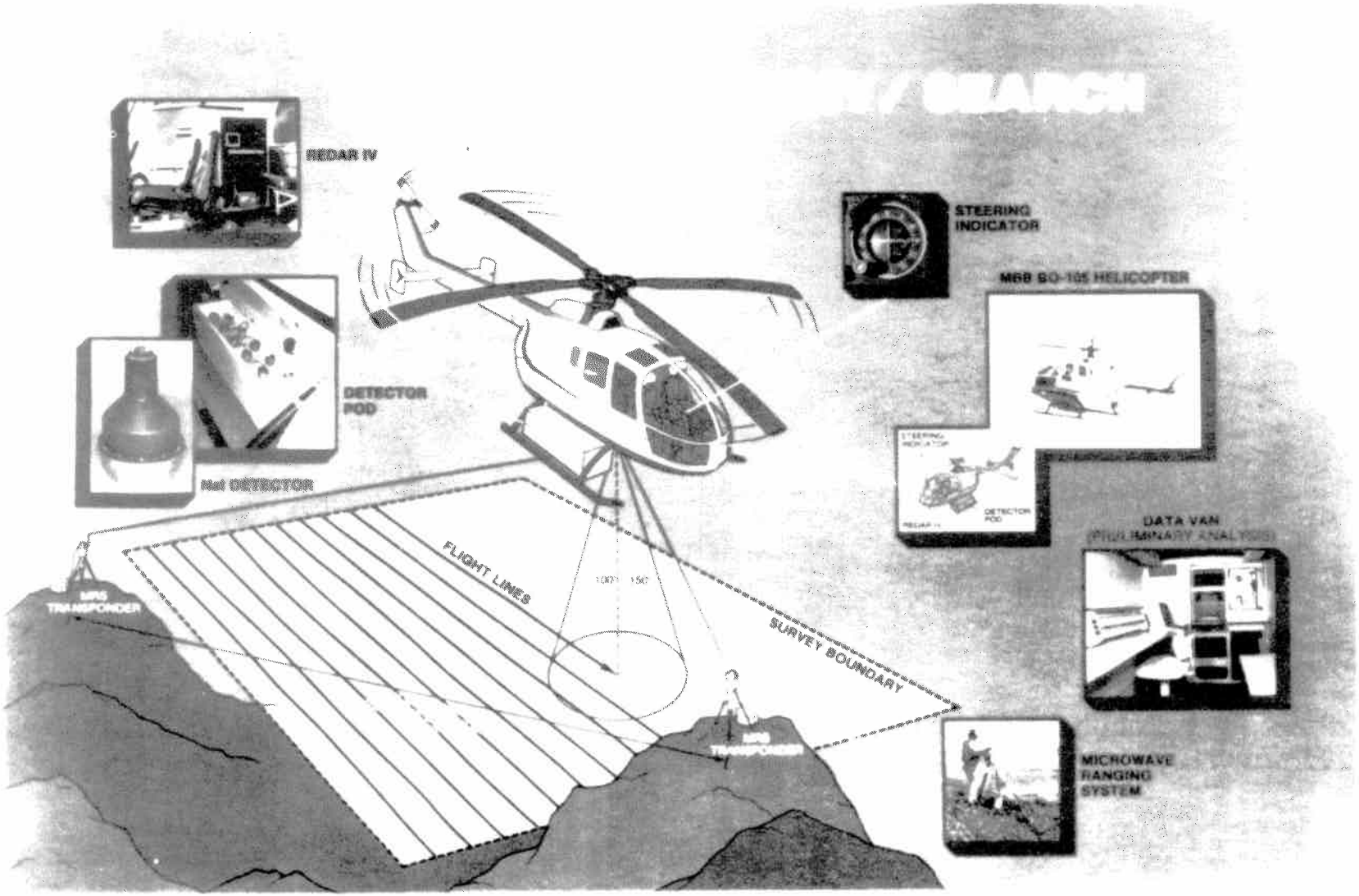

Figure 1. *WITH THE FIELD EQUIPMENT SHOWN HERE, A TYPICAL 5 × 5-MILE SURVEY CAN BE COMPLETED IN A FEW DAYS OF FLYING TIME*

Historically, Laboratory systems measured nuclear fallout from above-ground nuclear detonations. The high altitude and speed and range capability of fixed-wing platforms were needed; gross count data were adequate to the tracking task. But to find and identify a point source such as a lost or diverted weapon, an improvised nuclear device, or a radiation dispersal device—these tasks demanded more sensitive data acquisition; the low-level maneuverability of the helicopter; sophisticated, interactive analysis of specific portions of the gamma spectrum; and a whole generation of "smart," hand-held detector systems for close inspection. The new task is more demanding than the old. The urgency of this challenge will dominate Laboratory research for years to come.

The fourth and final change at the Laboratory is the trend to integrated remote sensing, i.e., the simultaneous use of several remote measuring systems at a given site. This provides a much broader range of information and greater accuracy. It gives the analyst more tools to probe the causes and effects of nuclear contamination.

The first step toward integrated remote sensing was the use of aerial photographs as base maps for radiation contour lines. It is not uncommon to survey a site for which there are no USGS maps or for which the existing maps are extremely old—in some cases 100 years old! We now use a carefully rectified photograph as a data base, usually one taken a few weeks prior to the survey by a Wild RC-10 camera from a Laboratory fixed-wing aircraft. The resultant radiation map can therefore be closely correlated with current land use, buildings, stream beds, roads, etc. Hence it is far more useful than data superimposed on outdated maps. Figure 2 shows a typical radiation survey map, overlaid on an aerial photograph of the site.

Recently acquired data are also being correlated with imagery from a Daedalus multispectral scanner, which acquires up to 11 simultaneous bands of data in the ultraviolet, visible, and infrared portions of the spectrum. Radiation data can now be correlated with vegetation types, vegetation vigor, specific land use patterns, and other important data which cannot be derived from color photographs. The analyst has still another tool for evaluating the impact of nuclear contamination on the biosphere.

These changes took place gradually. Advancing technology provided improved capability, more and better data, and more extensive analysis and interpretation. As the quality of the survey reports improved, the number of users expanded. They demanded still better equipment and more sophisticated output.

Many of these changes in operational philosophy and procedure are directly traceable to new or dramatically improved hardware and computer software. It is difficult to select the key items, those which have had the greatest impact on operations. I shall briefly discuss six, some of which are the subjects of detailed presentations by my colleagues.

1. The UHF Trisponder System, manufactured by Del Norte Technology, Inc., was recently tested at the Savannah River Plant with great success. The transceiver and Yagi antenna for a UHF remote unit are shown in Figure 3. This is an over-the-horizon time measurement system which uses spread spectrum or chirping transmission. The master transmitter/receiver, located in the survey aircraft, spreads energy over a 10-MHz bandwidth centered at 435 MHz. Two remote units, equipped with several six-element Yagi antennas, respond when interrogated by the master. The distance measuring unit then computes aircraft position with respect to the remote transmitters.

   The Laboratory previously used Del Norte's microwave ranging system to establish aircraft position. This was strictly limited to line-of-sight operation. Large surveys, done at low altitude over rugged terrain, had to be broken into several small, contiguous surveys. But the new UHF system has a range two to three times line-of-sight. It is accurate to ±2 meters to the line-of-sight and to +4 (−2 meters) to 75 km non-line-of-sight. When operationally deployed for routine survey work, the UHF Trisponder will dramatically improve the speed and convenience of aerial surveys in areas such as the Savannah River Plant.

2. Model IV of the Radiation and Environmental Data Acquisition and Recorder (REDAR) system, shown in Figure 4, was introduced several years ago. It is a multi-microprocessor, portable data acquisition and real time analysis system developed at the Laboratory. It simultaneously records nuclear radiation measurements, geographic position, and environmental data on cartridge tapes for post-mission analysis by mini-computer systems. Part of the data is processed in real

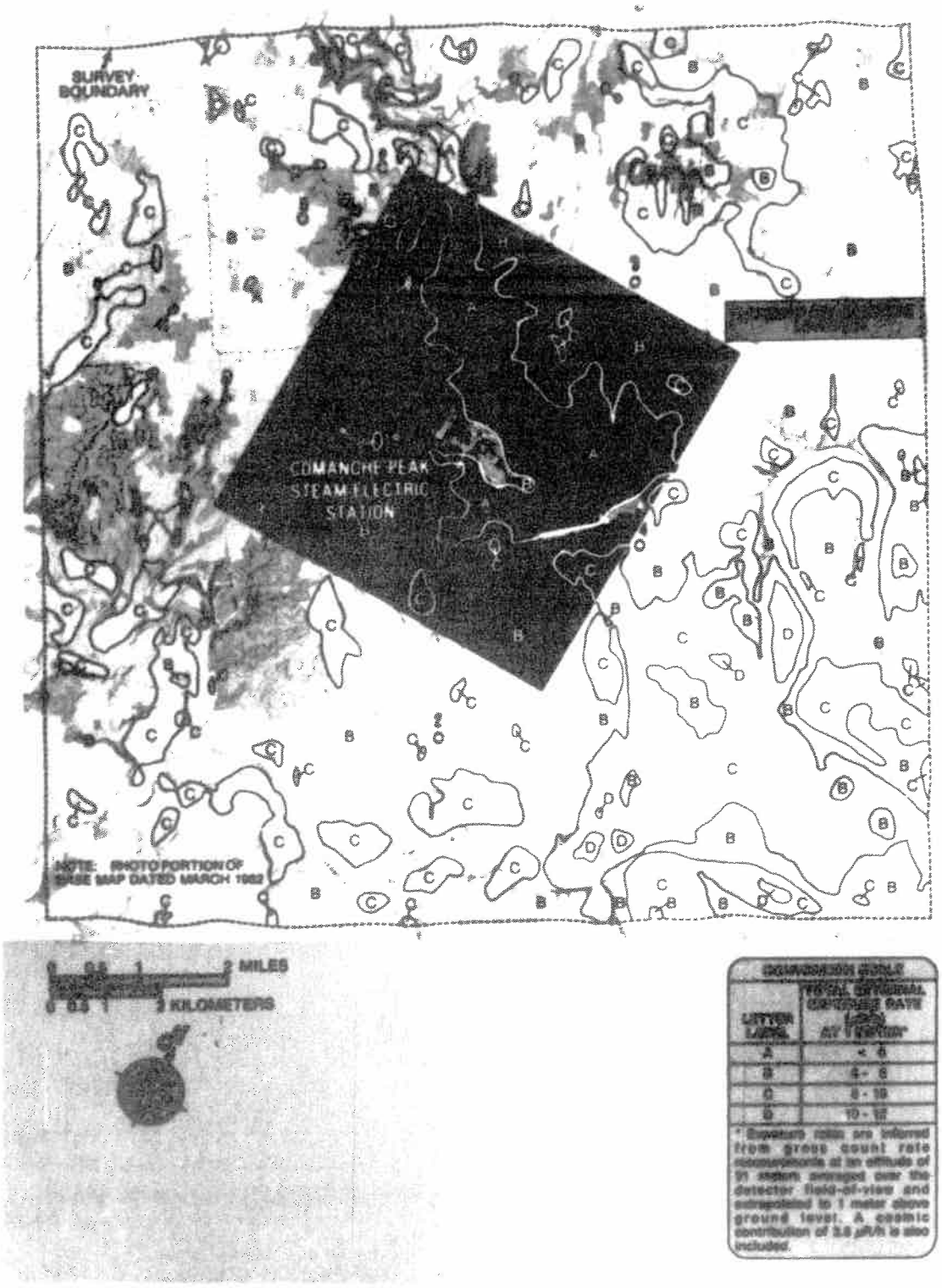

Figure 2. *TOTAL EXTERNAL EXPOSURE RATE CONTOURS DERIVED FROM AERIAL SURVEY DATA OBTAINED IN MARCH 1982 OVER THE COMANCHE PEAK STEAM ELECTRIC STATION, SOMERVELL COUNTY, TEXAS AND THE SURROUNDING AREA. Ground-based measurement locations are also indicated.*

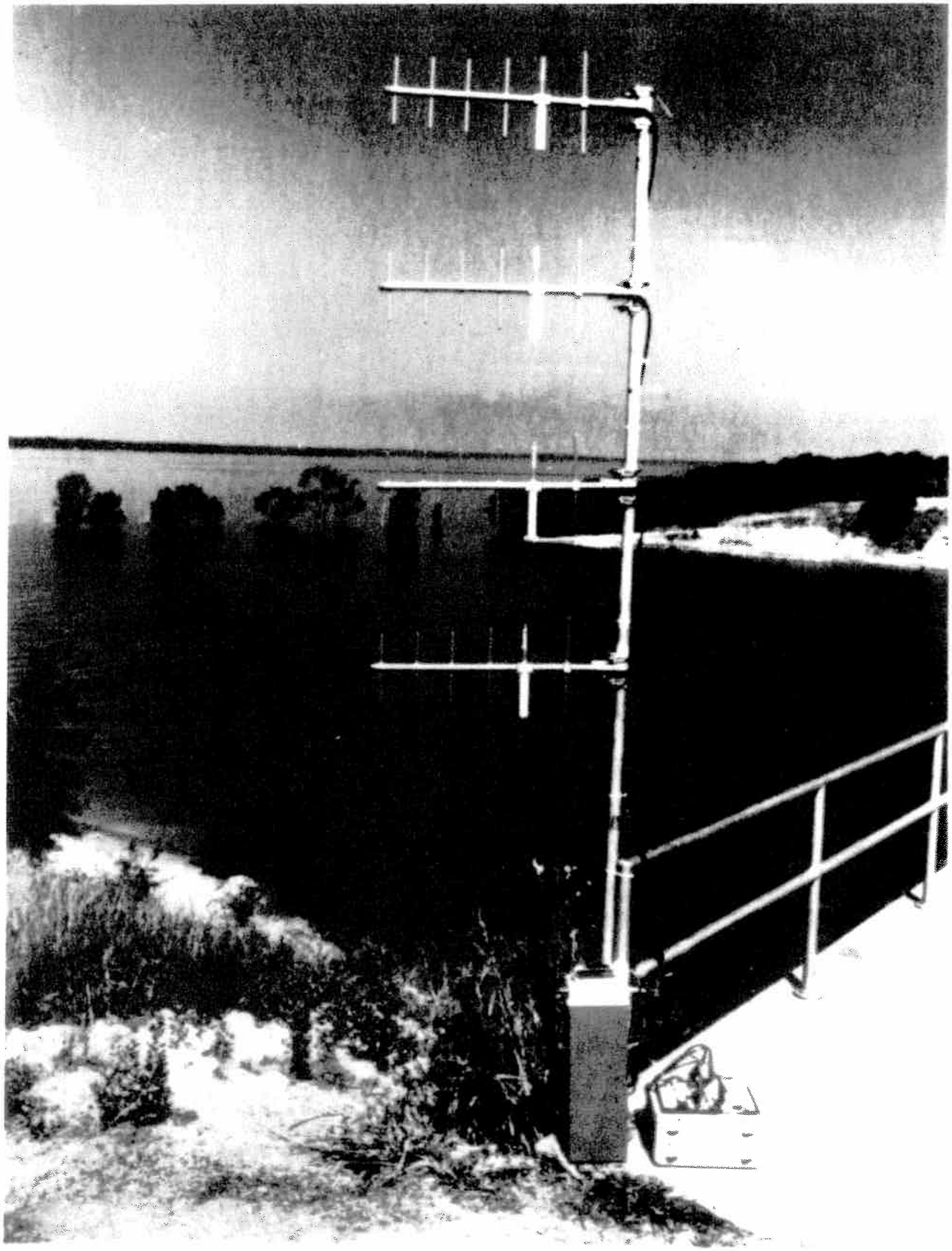

Figure 3. *THE DEL NORTE UHF TRANSCEIVER TYPICALLY USES AN ARRAY OF FOUR YAGI ANTENNAS.*

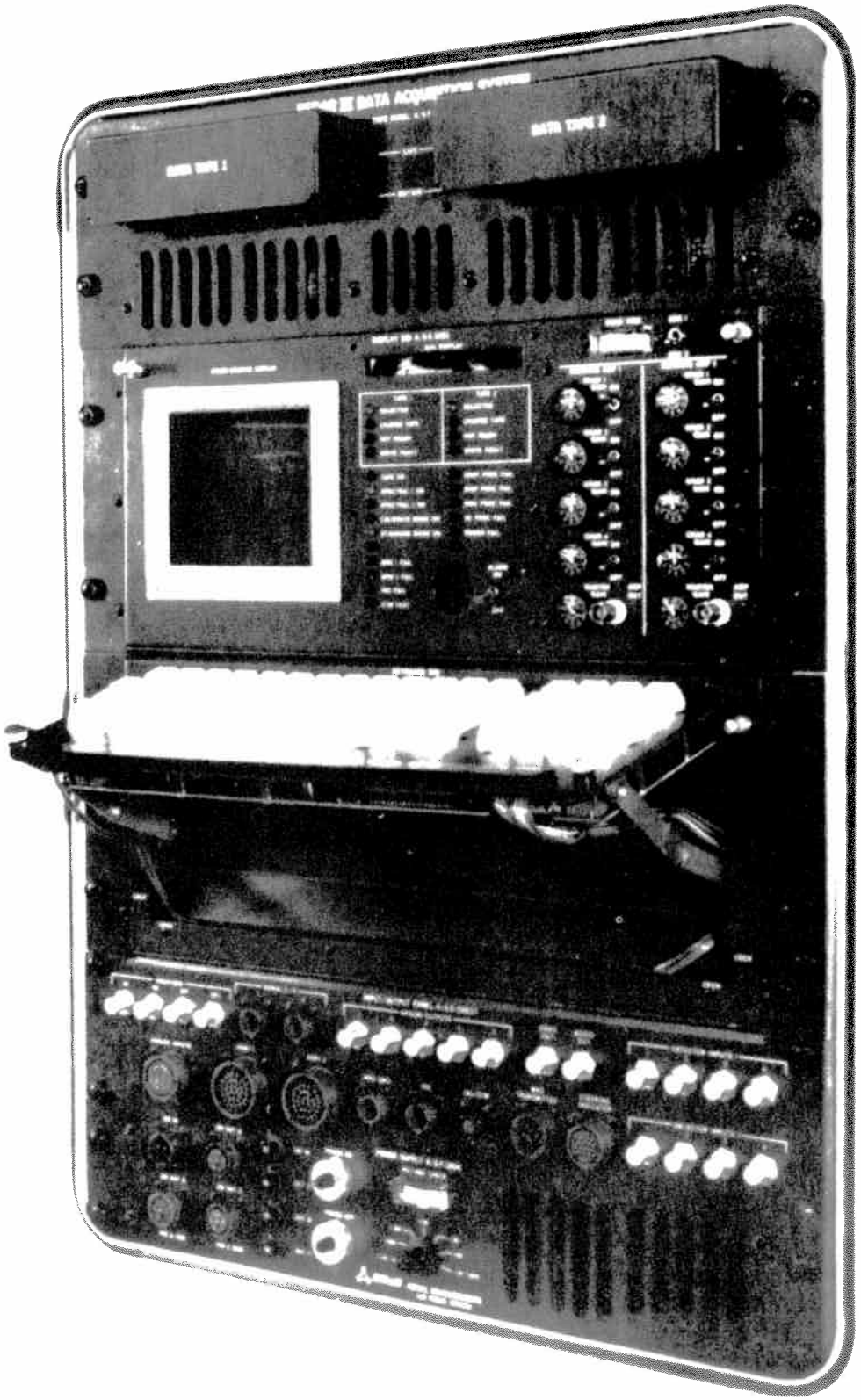

Figure 4. *GAMMA RADIATION DATA ARE ACQUIRED BY THIS REDAR IV SYSTEM MOUNTED IN THE HELICOPTER*

time and displayed on a CRT and multiple LED readouts. The REDAR system weighs only 46 kg. It was especially designed for use in the severe environments found aboard helicopters, fixed-wing aircraft, and various land-based field vehicles used by the Laboratory in radiation studies. It has proved very reliable under extreme operating conditions. REDAR is also highly flexible because the design is based on five Z-80 microprocessors, along with AM9511 arithmetic processing chips; these collect, analyze, display, and record the data. They also determine aircraft position and calculate steering signals for aircraft navigation. Because REDAR is fast, reliable, and accurate, the Laboratory has been able to dramatically shorten the duration of large area surveys in recent years while simultaneously improving the quality of the data reported. John Cleland will discuss REDAR IV in greater detail in a later paper.

3. The search algorithm is a powerful computer program built into the real time data analysis subsystem of the REDAR. It is used to search for areas exhibiting anomalous gamma or neutron radiation due to certain specific radionuclides. The algorithm was devised to detect these radionuclides with a moving detector in areas with spatially varying levels of background radiation. It is based on the fact that the shape of the spectrum from naturally-occurring radionuclides is quite constant; most of the nuclides of potential search interest cause a measurable perturbation of this natural spectrum shape.

   The search algorithm was devised to minimize operator setup time, interaction, and judgment. Individual photons are collected in energy windows, which are compared. Statistical computations are performed. When certain criteria are exceeded, audible and visual alarms are triggered. Currently the algorithm is programmed for 10 nuclides of probable interest, such as americium-241, plutonium-239, uranium-235, and cesium-137.

   The search algorithm vastly simplifies the task of searching for given nuclides. And it dramatically enhances detection sensitivity because the variable effects of operator skill and fatigue are minimized.

   T.P. Stuart, who is primarily responsible for many of the recent developments in search algorithm technology, will present a paper on the subject later in the symposium.

4. REDAC is the Radiation and Environmental Data Analyzer and Computer system used to process data acquired by REDAR IV. It has three basic configurations, which are shown in Figure 5: (1) Portable, for emergency response, at low production rates; (2) single-user, which is van-mounted and provides moderate production for routine surveys; and (3) multi-user, a multi-task, high production laboratory system. In the past few years extensive applications software has been developed for REDAC. Data analysts can generate isopleth contour plots, soil concentrations of specific radionuclides, gamma ray energy spectra, and inventories of total activity for any radionuclide of interest.

   REDAC software has been carefully adapted to the radiation detector characteristics. The techniques of statistical mathematics have been vigorously applied so that even the slightest trace of a radionuclide of interest can be found. The software has gradually evolved, encompassing a greater range of tasks with precision and accuracy.

   Thane Hendricks will discuss REDAC software in detail. However, I will mention one recent development which has had a dramatic impact on field survey procedures. This is the automatic contouring program developed two years ago.

   The survey helicopter normally flies parallel flight lines, spaced 250 feet apart, at an altitude of 150 feet. REDAR records gamma radiation data, and aircraft position and altitude, every second. The tape is quickly processed, in the field, by a mobile REDAC unit. Usually within three hours of aircraft landing the computer has generated an isopleth contour map accurately showing the total exposure rate at every point within the survey area. This map is immediately overlaid on a color aerial photograph of the site. Since both maps are exactly the same scale, analysis and interpretation can begin immediately. Areas of special interest can be quickly identified, to be reflown at lower altitude with finer line spacing, if necessary. Quite frequently areas of enhanced activity or

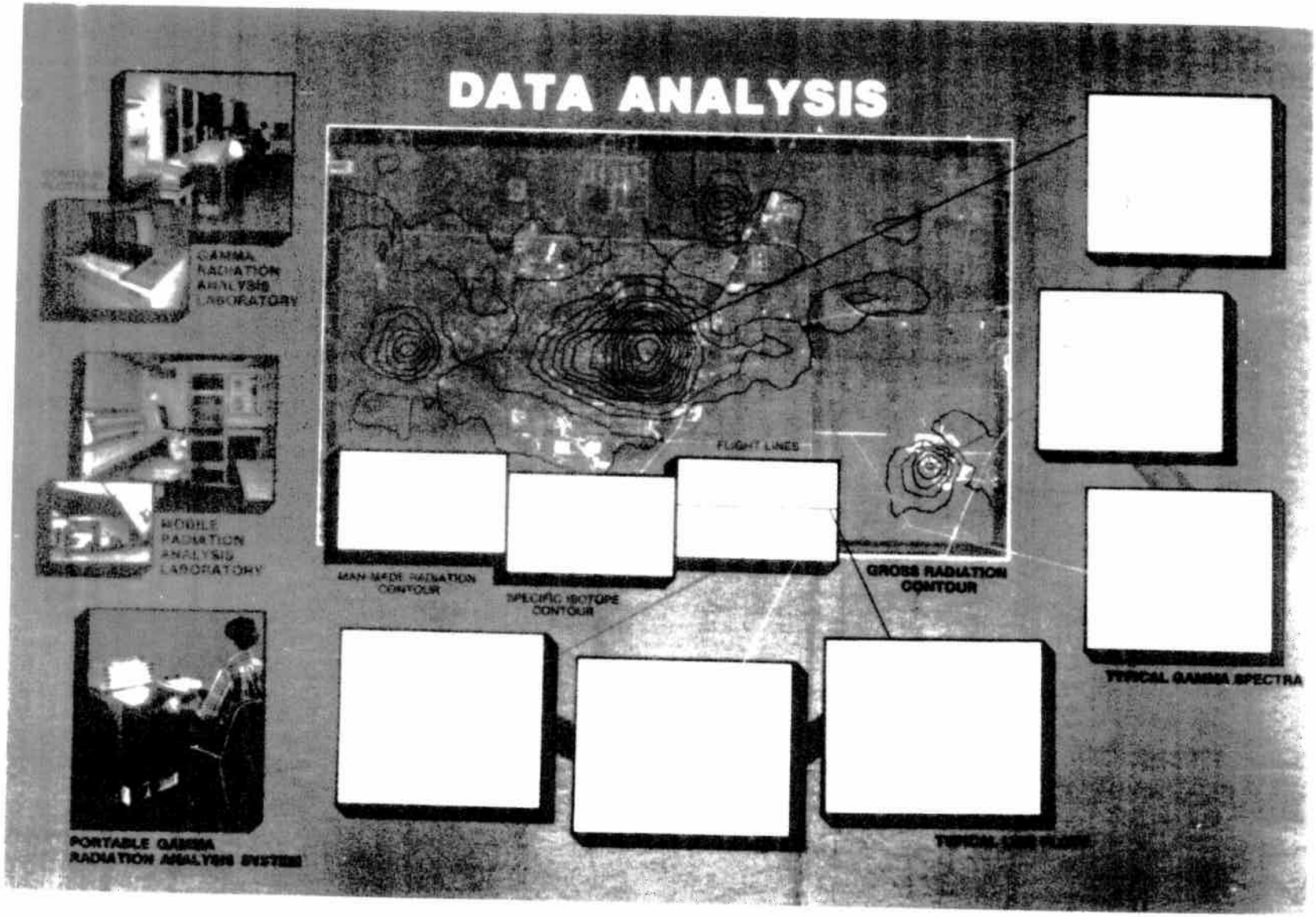

Figure 5. *COMPUTER ANALYSIS OF THE RADIATION DATA PROVIDES LINE PLOTS, GAMMA SPECTRA AND CONTOUR MAPS FOR ANY RADIOISOTOPE AT THE SITE*

special interest are found at the boundary of the planned survey. The boundary is usually extended in subsequent flights.

This automatic contouring program has provided the field team with extraordinary flexibility. It allows the project scientist to consult with representatives from the site and guarantees that all needed data are obtained before the survey team leaves the field. The value of the automatic contouring program is difficult to overestimate.

5. In the past two years the Remote Sensing Laboratory has made increasing use of extruded sodium iodide detectors, rather than single crystals of the same material. A typical pair of extruded detectors is shown in Figure 6. Extruded NaI(*Tl*) is frequently called Polyscin, which is a trademark of the Harshaw Chemical Company. Research data indicate that extruded detectors are three to five times stronger than single crystals. Single crystals have regularly failed in the Laboratory detector arrays because of thermal and mechanical shock. Early indications are that extruded detectors offer a considerable advantage in reliable performance and fracture resistance.

   Since extruded detectors are usually cast in convenient shapes, such at 4 × 4 × 16-inch "logs," individual detectors can be densely packed in arrays. This is quite convenient for search vehicles and offers the possibility of shielding and directional sensitivity. Extruded detectors also offer improved counting statistics at higher gamma ray energies. Our current research indicates that we can expect improvement in detection range for special nuclear materials.

6. The last item I shall mention is the graphic overview system, which is a compilation of photos, maps, overlays, and summary information from environmental programs at a given site. Colored overlays are superimposed on various base maps or photographs to show liquid and airborne release points, on-site storage locations, monitoring locations, aerial survey results, population distribution, wind roses, water drainage, vegetation, and a wide variety of related information. An example of such overlays is shown in Figure 7. Graphic overview packages have proved to be extraordinary tools for understanding, analyzing, and presenting complex environmental interactions at a site.

There are many other innovations in hardware, software, and procedures which cannot be adequately treated in a review article. However, these six developments have made a dynamic contribution to airborne radiometric technology at the Remote Sensing Laboratory in the past few years.

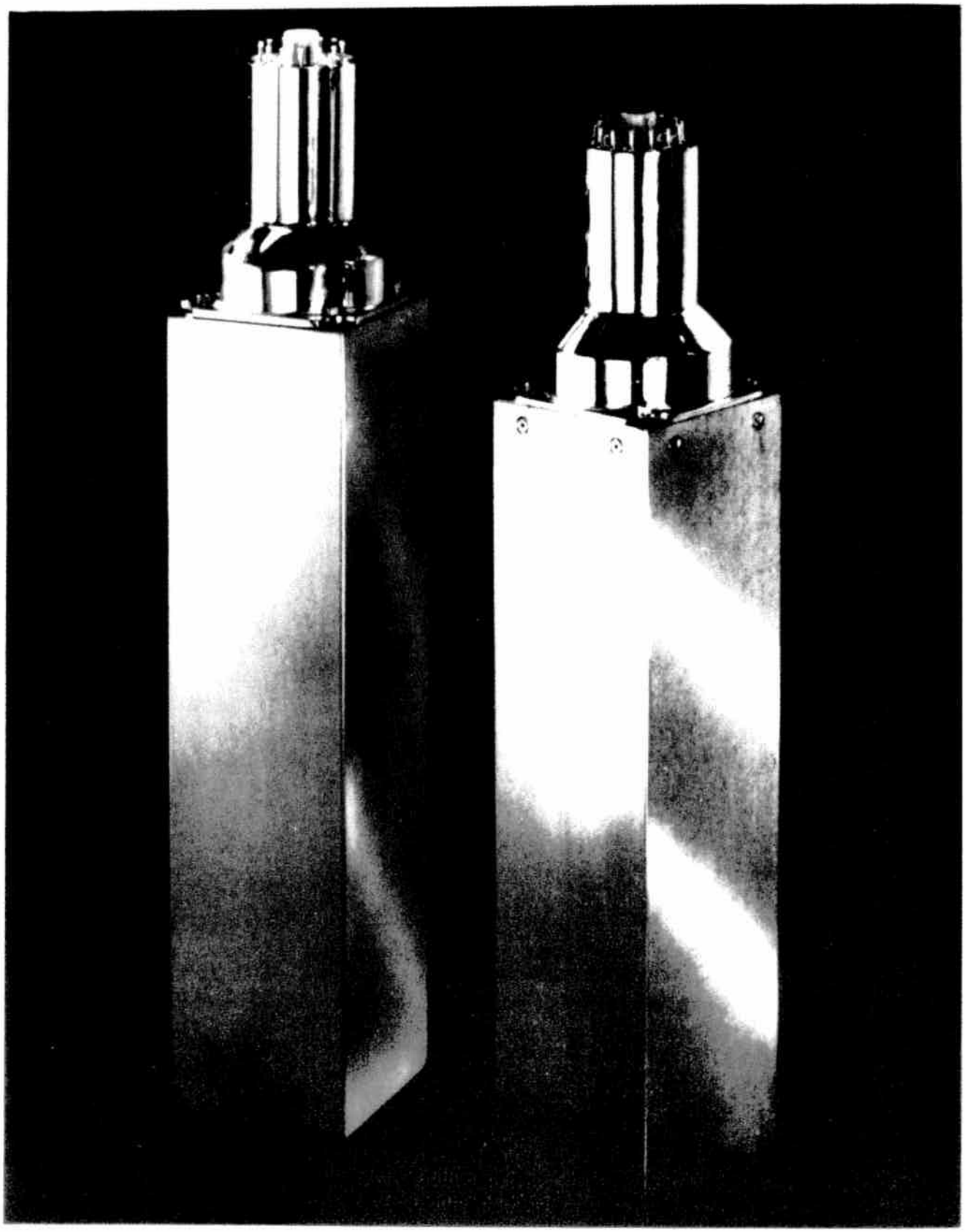

Figure 6. *THESE HARSHAW 4 × 4 × 16-INCH NAI "LOGS," WITH ATTACHED PHOTOMULTIPLIERS, ARE DENSELY PACKED IN GAMMA DETECTOR ARRAYS*

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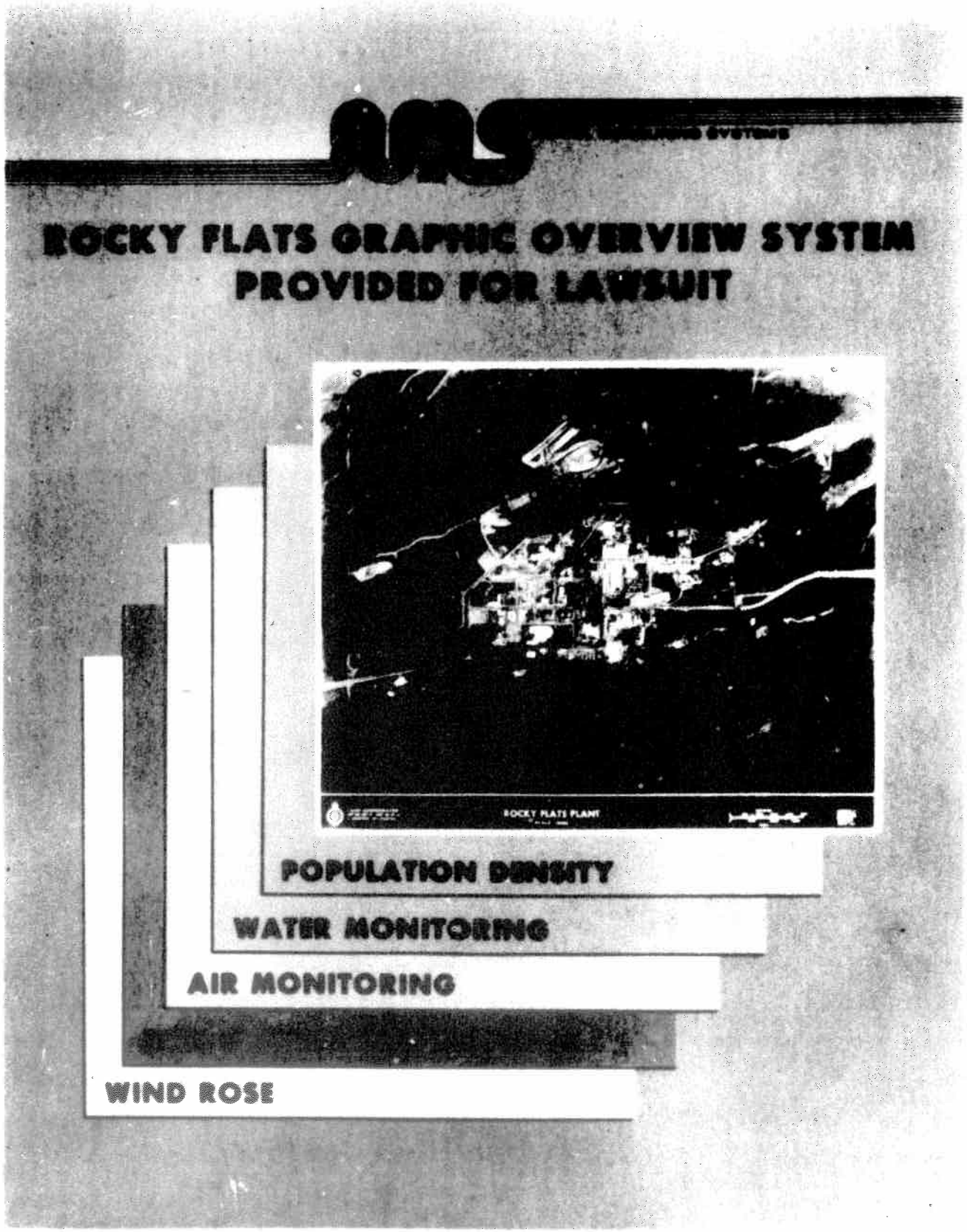
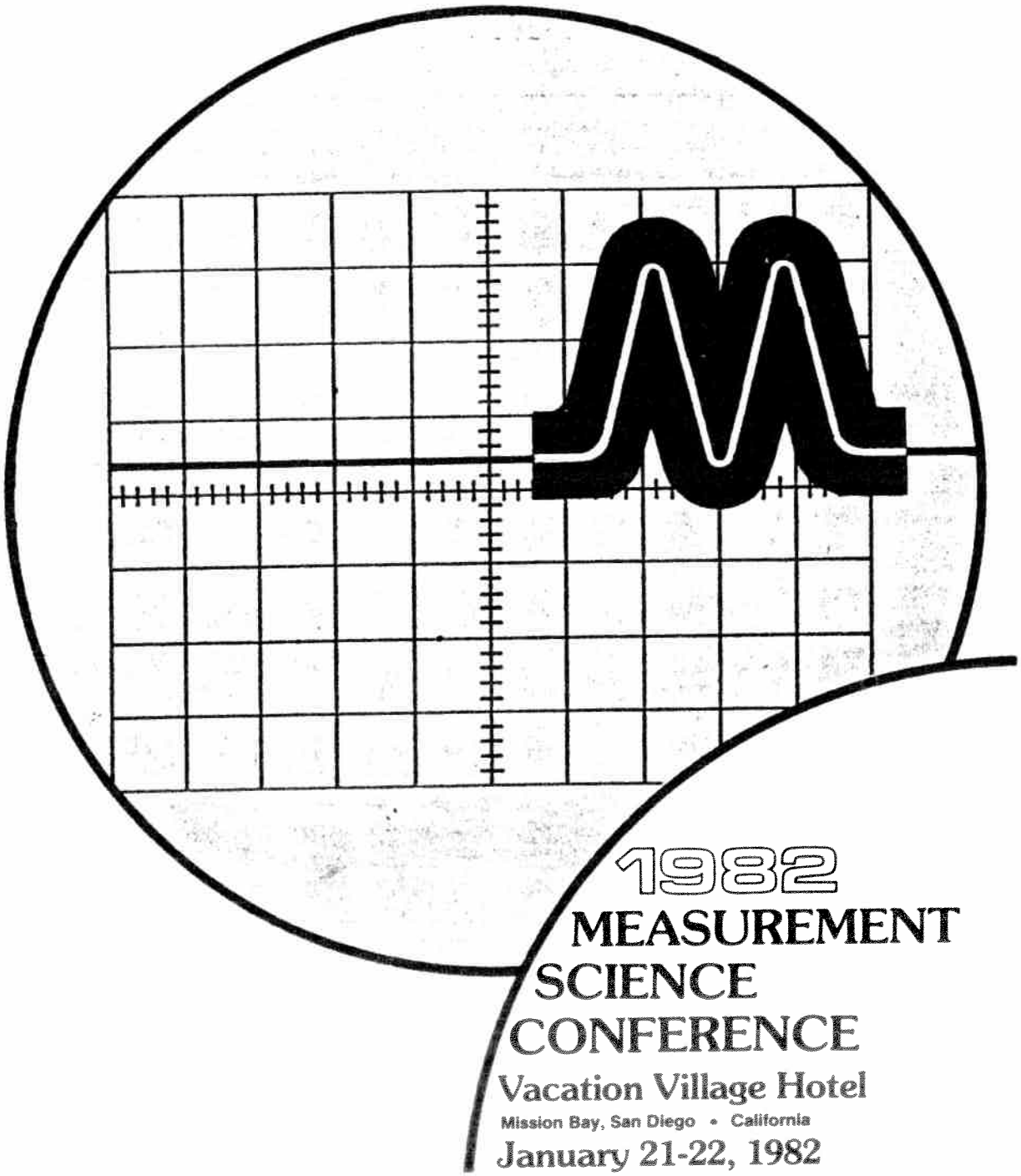


Figure 7. *EACH SITE'S BASE PHOTOGRAPH IS PROVIDED WITH MULTIPLE TRANSPARENT OVERLAYS AS AN AID TO RAPID SITE ANALYSIS*

PROCEEDINGS



INNOVATIVE MEASUREMENT — TODAY'S REQUIREMENT

REDAR: THE RADIATION AND ENVIRONMENTAL DATA ACQUISITION AND RECORDER SYSTEM

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ABSTRACT

REDAR (Radiation and Environmental Data Acquisition and Recorder), Model IV, is a multi-microprocessor, portable data acquisition and real time analysis system. It was recently designed for use in severe environments aboard helicopters, fixed-wing aircraft, and various land vehicles. Nuclear radiation measurement, geographic position, and environmental data are simultaneously acquired, displayed on a CRT and multiple LED readouts, and recorded on cartridge tapes for post mission analysis on minicomputer systems.

INTRODUCTION

Since World War II, radioactive materials have grown from laboratory curiosity to major industry. Even in the early years it was recognized, especially by those in science and the military, that natural or man-made dispersions of radioactive materials would require airborne detection systems. As early as 1948, aerial measurements of surface radioactivity were made to determine the feasibility of airborne prospecting for radioactive ore deposits (1). The U.S. Geological Survey (USGS) and the Oak Ridge National Laboratory cooperated with the Division of Biology and Medicine of the U.S. Atomic Energy Commission (AEC) in these early studies (2). Such systems grew in size and sophistication. They were highly effective in tracking radioactive clouds released in the Weapons Test Program at the Nevada Test Site.

The USGS ultimately asked the AEC to relieve them of radioactive cloud tracking responsibility. In 1959 the AEC requested EG&G Inc. to develop a second generation system. Under EG&G's Aerial Measuring Systems (AMS) and Nuclear Emergency Search Team (NEST) programs, radiation measurement hardware has undergone continuous and dramatic improvement (3).

These programs are the driving forces within the U.S. Department of Energy Remote Sensing Laboratory (RSL) in Las Vegas, where a broad range of aerial research and development studies are conducted. The Laboratory recently deployed Model IV of REDAR, the Radiation and Environmental Data Acquisition and Recorder system.

REDAR (4) is a multi-microprocessor, portable data acquisition system. Nuclear radiation measurements, geographic position, and environmental data are simultaneously acquired. Data are processed in real time and displayed on a CRT (a) and multiple LED (b) readouts. They are also recorded on cartridge tapes for post mission analysis in minicomputer systems. REDAR was especially designed for use in the severe environments found aboard helicopters, fixed-wing aircraft and various land-based field vehicles used by the RSL on radiation search missions throughout the U.S., in Canada, Mexico, the mid-Pacific and elsewhere. The objective of this article is to describe the components, the functions and the performance of the unique REDAR IV system.

GENERAL DESCRIPTION

REDAR IV is the newest data acquisition system designed and fabricated by the RSL. It has been actively deployed for over a year in several dozen radiation survey missions. The entire unit, shown in Figure 1, is contained in a rugged, water resistant fiberglass case with removable front and rear covers. Total weight is 46 kg. It displays to the operator all the radiation and system information, in real time, on a 5-inch CRT display and multiple LED readouts. All pertinent data are recorded on magnetic tape cartridges (c) for post mission analysis in a minicomputer system (3).

Central to the REDAR design are five Z-80 microprocessors (d), along with the AM9511 arithmetic processing chips (e) to perform the collection, analysis, display and recording of data, as well as determine aircraft position and calculate steering signals for aircraft navigation. The five microprocessors in REDAR are known as the control, display, single channel, tape, and steering processors. The system allows operator access to the main processor buss through both serial and parallel data ports under control of the control processor.

(a) Cathode ray tube
(b) Light-emitting diode
(c) Scotch DC-300XL data cartridge, 3M Company, Minneapolis, MN
(d) Zilog, Inc., Cupertino, CA
(e) Advanced Micro Devices, Sunnyvale, CA

Functionally, REDAR can be divided into six subsystems (see Figure 2):

1. Two independent radiation data collection systems
2. A general purpose data I/O system
3. A tape recording system
4. A CRT display system
5. A real time data analysis system
6. A microwave ranging and steering indicator system.

Radiation data are typically obtained from sodium iodide crystals with attached photomultiplier (PM) tubes. Gamma rays which penetrate the sodium iodide generate light pulses; these pulses are converted to electrical pulses and amplified in the PM tube. The output of the PM tube is amplified, pulse-shaped, and fed into the REDAR.

Normally, a radiation survey helicopter is equipped with twenty 12.7 cm diameter by 5.1 cm thick sodium iodide crystals. The outputs of nineteen crystals are combined and fed into one data collection channel; the remaining crystal output is fed to the second channel. This arrangement permits the REDAR to handle an extremely broad dynamic range in nuclear radiation intensity.

MODULAR COMPONENTS

The REDAR IV consists of five standard height EIA (f) modules; for each the height is listed in parentheses.

1. Tape drive (13.3cm)
2. Display (17.8 cm)
3. Keyboard (17.8 cm)
4. I/O connector (8.9 cm)
5. Power supply (8.9 cm)

The total rack height is 66.7 cm. The weight is 46 kg, excluding detectors, special power supplies, cables, etc.

The tape drive module contains two type R1, 4-track parallel cartridge magnetic tape drives (g). The drives are wired in parallel. When one tape is filled, the tape controller automatically switches to the other tape and generates a warning signal. The operator then replaces the first to continue the cycle.

The display module contains a black and white 5-inch TV monitor, the TV display CPU (central processing unit) logic, the single channel CPU and logic and 2 ADCs (analog-to-digital converters) with their peak followers. A 5-inch color monitor will be available in the future as an option. The display panel shows selected parameters on a 16-character alphanumeric LED readout. LED indicator lights flag the function or failure of critical components and subsystems. Finally, there are audio indicators for alarms.

The keyboard module is a full ASCII (h) keyboard, plus a 16-key special function keyboard which permits control of various system parameters with a single stroke. This keyboard panel is hinged; it will lock in a tilted position for ease of operation.

Behind the keyboard is a printed circuit card cage which houses the tape processor, the control processor, memory, the analog input card, the MRS/INS (i) card, the five channel DAC (digital-to-analog converter), the keyboard buffer, the serial I/O, the two DMU (j) cards, two counter cards and two spectral memories. Since the REDAR operator normally sits in the helicopter cockpit, the system is usually controlled with a remote keyboard which also serves as a clipboard for the mission log.

The I/O panel has all the connectors to link the REDAR IV to ancillary equipment. However, connections to the power supply are made at the rear of the module.

Since REDAR is designed specifically for the aircraft environment, the power supply module requires a +28v dc input at a maximum of 15 amps. Voltages required within the system are generated with internal high efficiency dc-to-dc converters (k). There is an internal logic board which shuts the REDAR down if the input 28v dc supply is outside acceptable tolerances. The input 28v and all internal voltages can be monitored on a meter. Three output connectors are available for ancillary equipment, such as strip chart recorders and the low and high voltage power supplies for the gamma detector arrays.

RADIATION DATA COLLECTION SUBSYSTEM

As indicated above, there are two separate detector systems: one consisting of 19 gamma detectors, the other with a single crystal. The preamplified and summed outputs from these two are fed to dual four-channel linear amplifiers, then into dual pulse height analyzers (PHAs). The data flow is schematically shown in Figure 3. The PHAs are high speed peak followers coupled to low power, high speed 16-bit successive approximation ADCs. Each peak follower PC board contains the high speed peak-following circuitry to interface to an ADC (l), a 10-bit to 8-bit tape data compression EPROM (m) and buss buffers. The ADCs perform two 8-bit conversions to achieve 16-bit accuracy in a total time of 6 microseconds for all 16 bits. The 10 most significant bits are used, the remaining 6 are truncated. This gives a successive approximation ADC with a differential linearity comparable to a Wilkinson ADC. The busy time of this ADC is fixed at 6-7 microseconds instead of the pulse-height-dependent busy time of a Wilkinson unit. This feature provides easy post-mission busy (dead) time corrections to the radiation data.

The most significant 10 bits are routed to the tape data compressor, the display system, and the analysis system. The data compressor converts 10 bit, 1024 channel PHA data to a 3-segment, 8-bit,

(f) Electronic Instrument Association
(g) Series CMTD-3000R2, Data Electronics, Inc., Pasadena, CA
(h) American Standard Code for Information Interchange
(i) Microwave ranging system/inertial navigation system
(j) Distance measuring unit
(k) Powercube Corp., Billerica, MA
(l) Phoenix Data, Inc., Phoenix, AZ
(m) Erasable, programmable read only memory

256-channel format. The first segment spans the gamma energy range from 0 to 300 keV; each channel represents a 4-keV energy bin. In the second segment each channel is 12 keV wide; in the third, each channel is 36 keV wide. This spectral compression scheme is shown in Table 1.

Table 1. REDAR Spectral Data Compression

Input (keV)	Channel Input	Energy Coefficient $E\left(\frac{keV}{channel}\right)$	Compressed Channel Output
0-300	0-75	4	0-75
304-1620	76-405	12	76-185
1624-4068	406-1017	36	186-253
4072-cutoff	1018-1023	N/A	254
cutoff	forced to zero	N/A	255

This three-segment compression allows low and high energy measurements to be made simultaneously. It also reduces the amount of required storage space by a factor of 4.

The 8-bit, 256-channel data are routed from the compressor to dual 1024-word by 16-bit spectral accumulators, each of which is divided into 4 blocks. Each block represents 1 second or 250 milliseconds of data, depending upon the mode of operation. In the normal mode, spectral data are output every second; in the calibration mode, data are output every 250 milliseconds.

These data are stored in four 1-second blocks or four 250-millisecond blocks in the spectral accumulators. One of the dual spectral accumulators accumulates data while the other is output to tape, i.e., they operate in a flip-flop mode. This results in continuous data collection because the switch from memory to memory is completed in a few microseconds (they are double-buffered). Various signals are sent from the PHA to an array of counters which record the gross count and live time. The live time is the real time, minus PHA busy time (which is also known as dead time). The gross count is the sum of all pulses larger than a low level discriminator, which is usually set at 28 keV. The counter boards are read out at one-second intervals by the control processor for output and display. Radiation data obtained from neutron detectors are input to the REDAR through counters 1 and 2 (see Figure 3).

CONTROL PROCESSOR SUBSYSTEM

The control processor ties all of the REDAR subsystems together and performs all data I/O functions. It has access to a maximum of 64k bytes (n) of EPROM and 18k of RAM (random access memory). The latter includes 8k of battery-backed-up RAM, the dual port memories of the other subsystems, and 2k bytes of spectral data accumulators.

Communication between REDAR subsystems is governed by a complex protocol which insures that two processors cannot address the same memory location simultaneously. This protocol is a series of message blocks with status records; the status record must be checked prior to accessing the message block. The control processor continually scans these status blocks for messages and passes such messages to the appropriate destination. If the control processor is the destination, it performs the desired function.

The keyboard may be assigned directly to any of the subsystems. Hence, the operator can enter or retrieve information in the control, real time analyzer, tape, display or MRS processors. Ports may be assigned at the console to permit remote operation via a terminal or keyboard with a video monitor driven from the remote video output. During survey missions the operator monitors REDAR operation on a CRT mounted in the helicopter instrument console and controls the system with a clipboard/keyboard in his lap.

The control processor has two major operational modes: interrupt and background. The interrupt mode controls execution of various time dependent routines, keyboard entries, data I/O through RS232 ports. It also maintains the real time clock, which generates an interrupt signal every 125 milliseconds. The interrupt calls a routine that checks time and executes other routines, such as reading and clearing counters, etc. The background mode handles messages passing between other subsystems and non-time-dependent routines.

The control processor communicates to the operator via:

1. Two serial RS232 ports, each independently programmable from 300-9600 baud;
2. Five analog outputs driven by 8-bit DACs;
3. Eleven analog inputs which are scaled, multiplexed, and digitized by a 10-bit DAC;
4. The console keyboard:
5. A TV monitor with a remote video output;
6. A 16-character ASCII LED display;
7. A parallel port to the control processor (this requires an optional card which is not yet available).

TAPE RECORDING SUBSYSTEM

The tape recording subsystem writes and checks data passed to the tape processor by the control processor. The dual recorders are DEI 4-track parallel cartridge tape recorders, operated at 30 ips (o), with 1600 BPI (p) density.

The tape processor inputs a maximum of 4096 bytes passed to it by the control processor and writes them on one of the recorders. The tape processor controls tape management, selects tape decks, and outputs tape error messages. Status messages are sent through the control processor to the TV and front panel devices, such as the LEDs and alphanumeric displays. At the end of a tape, this processor automatically switches to the other recorder and generates a change-of-tape message for the operator.

(n) 8-bit words

(o) Inches per second
(p) Bits per inch

CRT DISPLAY SUBSYSTEM

The CRT display system inputs data from the control processor through a 1k byte dual port memory and from the display spectral accumulator. These data are formatted and transmitted to one or more TV monitors in a standard NTSC (q) format. Several display formats are used: pure alphanumeric, mixed alphanumeric and graphic, or pure graphic. Reverse video displays highlight error and warning messages. The normal format is a gamma ray spectrum display of 115 locations vertically by 256 locations horizontally, plus twelve 16-character alphanumeric displays for selected parameters. The operator may choose any of twelve system parameters by keyboard commands to the display processor.

The gamma spectrum is displayed in a bar graph mode; 256 channels are displayed, with vertical amplitude indicating the relative number of counts for that channel and horizontal position correlated with gamma ray energy. Two movable markers may be used to indicate the exact energies of gamma peaks in the spectrum. The CRT display formats may be changed without affecting the data, since it is stored in memory.

SINGLE CHANNEL REAL TIME ANALYSIS SUBSYSTEM

The single channel analysis system presents information, in real time, generated by resident physics algorithms. This system has accumulators which can be software configured to include various energy windows. Each window consists of a number of channels and, therefore, spans a gamma ray energy band. A maximum of 30 non-overlapping or overlapping windows can be assigned by the single channel processor.

Resident physics algorithms select appropriate windows and apply weighting factors to extract gamma photopeak count rates for radioisotopes deposited on the terrain below the helicopter. Since these are processed and displayed in real time, alert signals are given to the REDAR operator that an anomaly has occurred. Hence, additional survey time can be immediately accumulated over the anomaly, and the operator can guide detailed data analysis during post mission computer analysis.

MICROWAVE RANGING AND STEERING SUBSYSTEM

The microwave ranging portion of this subsystem generates and receives all necessary timing signals to and from the MRS master transponder, which is located in the helicopter. The master interrogates two remote transceivers mounted on towers, hills or tall buildings outside the survey area (r). By measuring the roundtrip propagation time between the master and the remotes, this system can calculate the range to each. These ranges are passed to the control processor via a 1k byte duel port memory for output on tape, CRT display, etc.

(q) National Television Standards Committee
(r) Trisponder/202a, Del Norte Technology, Inc., Euless, TX

The steering portion of this subsystem uses these ranges and a coordinate system established by the REDAR operator to calculate the desired flight paths for the survey mission. Coordinate system parameters are entered on the keyboard or from a battery-backed-up RAM so that the operator has to manually enter only parameters which have been changed.

The steering information can be displayed on the CRT, the five analog outputs for an x-y plot or strip chart display, and through a separate I/O panel connector to an ILS (instrument landing system) meter presentation to the pilot. Left/right deviations of the vertical needle indicate corresponding departures from the programmed flight path. Up/down deviations of the horizontal needle indicate deviations from the desired survey altitude. Altitude information is obtained from the helicopter radio altimeter, which measures the time lag for the return of a pulsed signal to the ground. The sensitivities of the horizontal and vertical needles can be independently programmed to suit mission requirements.

The microwave ranging system depends critically on line-of-sight communication between the master and both remote transceivers. For survey missions with extreme variations in altitude, the MRS system provides insufficient data to the ILS meter for proper navigation. For these cases, an INS (s) is installed aboard the helicopter. When MRS input fails, the ILS meter locks up, i.e., no navigation data are provided. But position information from the INS is continuously recorded on tape. This allows post flight recovery of the actual aircraft position. The MRS is used as an absolute reference to determine a drift curve for the INS; aircraft position is obtained from corrected INS data.

SUMMARY

The U.S. Department of Energy Remote Sensing Laboratory in Las Vegas, Nevada, has developed a state-of-the-art data acquisition and recorder system called REDAR. The system includes five Z-80 microprocessors. It is built to withstand the severe environments encountered in helicopters and other field survey vehicles. REDAR is a highly flexible acquisition system, capable of recording gamma ray and neutron radiation data, aircraft position and environmental data simultaneously. It provides navigation guidance to the aircraft pilot, and since it also performs real-time data analysis, REDAR is a highly effective search tool for radiation sources. REDAR is light in weight, easy to program and control, capable of recording multiple inputs. Because of its exceptional capabilities, REDAR IV is expected to serve as the RSL's primary data system for many years.

REFERENCES

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(s) LTS-51, Litton Systems, Inc., Woodland Hills, CA

2. Dunning, G. M. and Hilcken, J. A. (Eds.), "The Shorter-Term Biological Hazards of a Fallout Field," proc. of U.S. Atomic Energy Commission and U.S. Department of Defense symposium, GPO, Washington, D.C. 12-14, 1958.

3. Jobst, J. E., "The Aerial Measuring Systems Program," Nucl. Safety. Vol. 20, No. 2, March-April 1979, pp. 136-147.

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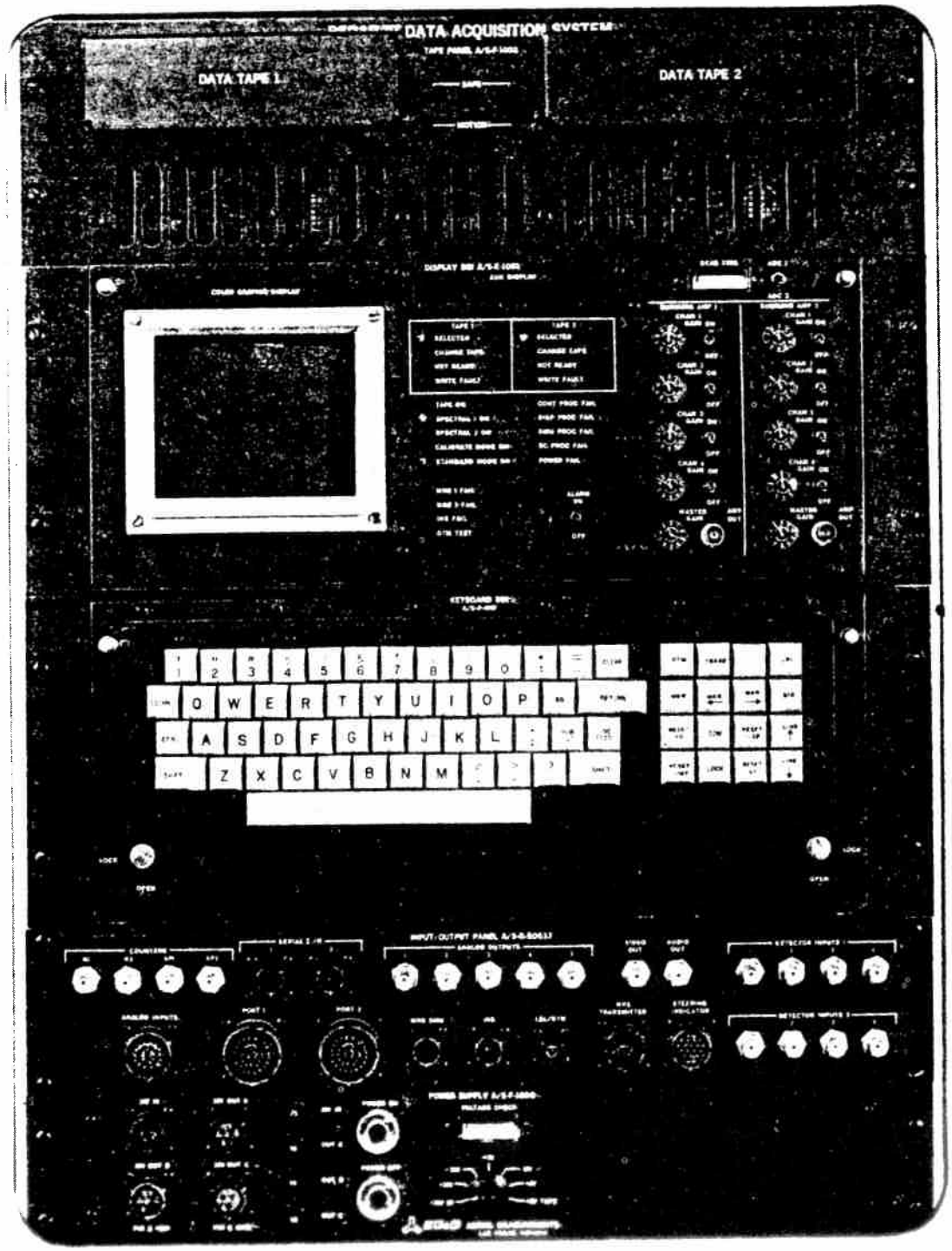

Figure 1. REDAR IV consists of five modules (top to bottom): tape, display, keyboard, connector and power supply.

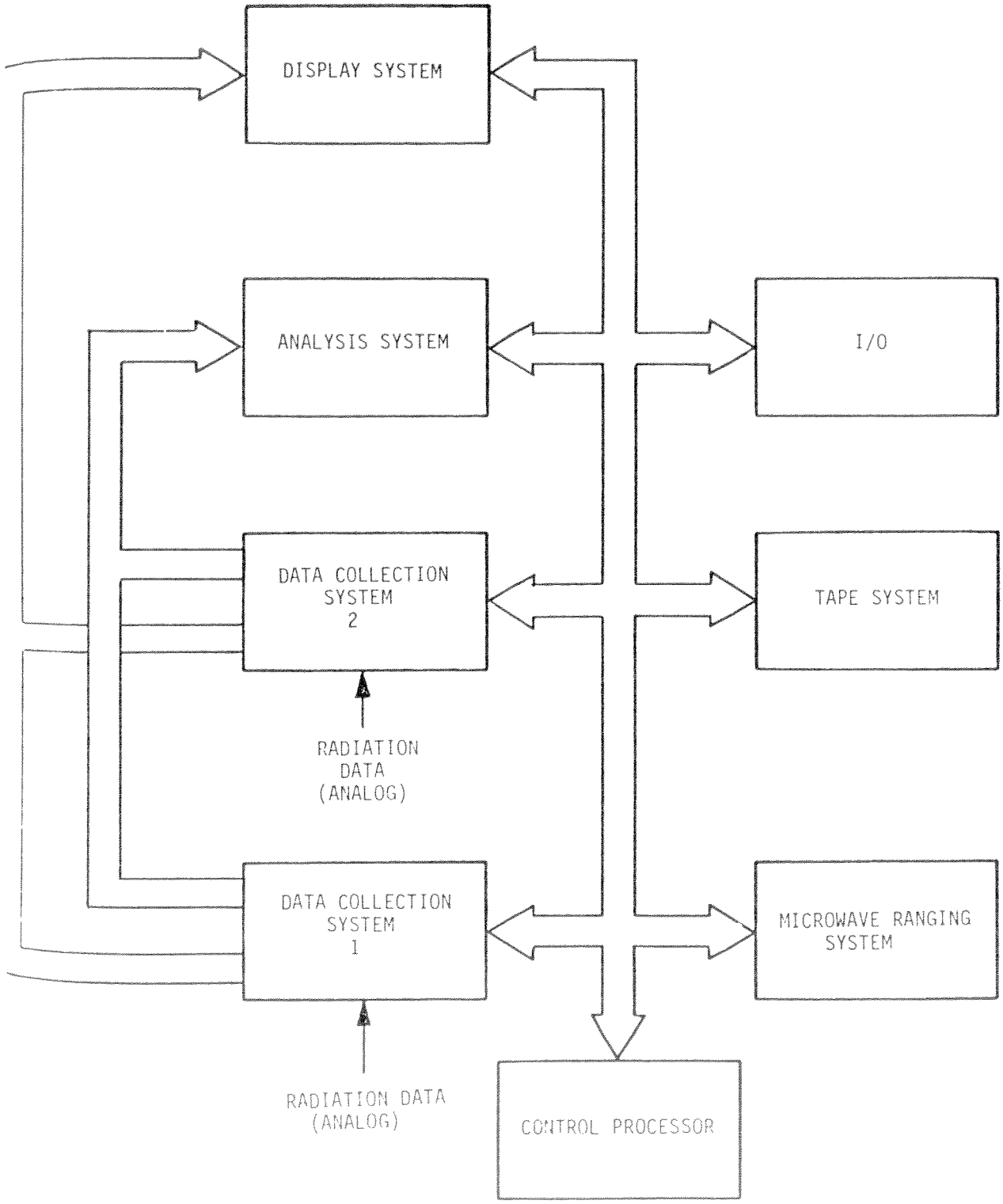

Figure 2. REDAR IV contains five Z-80 microprocessors: control, tape, display, single channel and microwave ranging and steering.

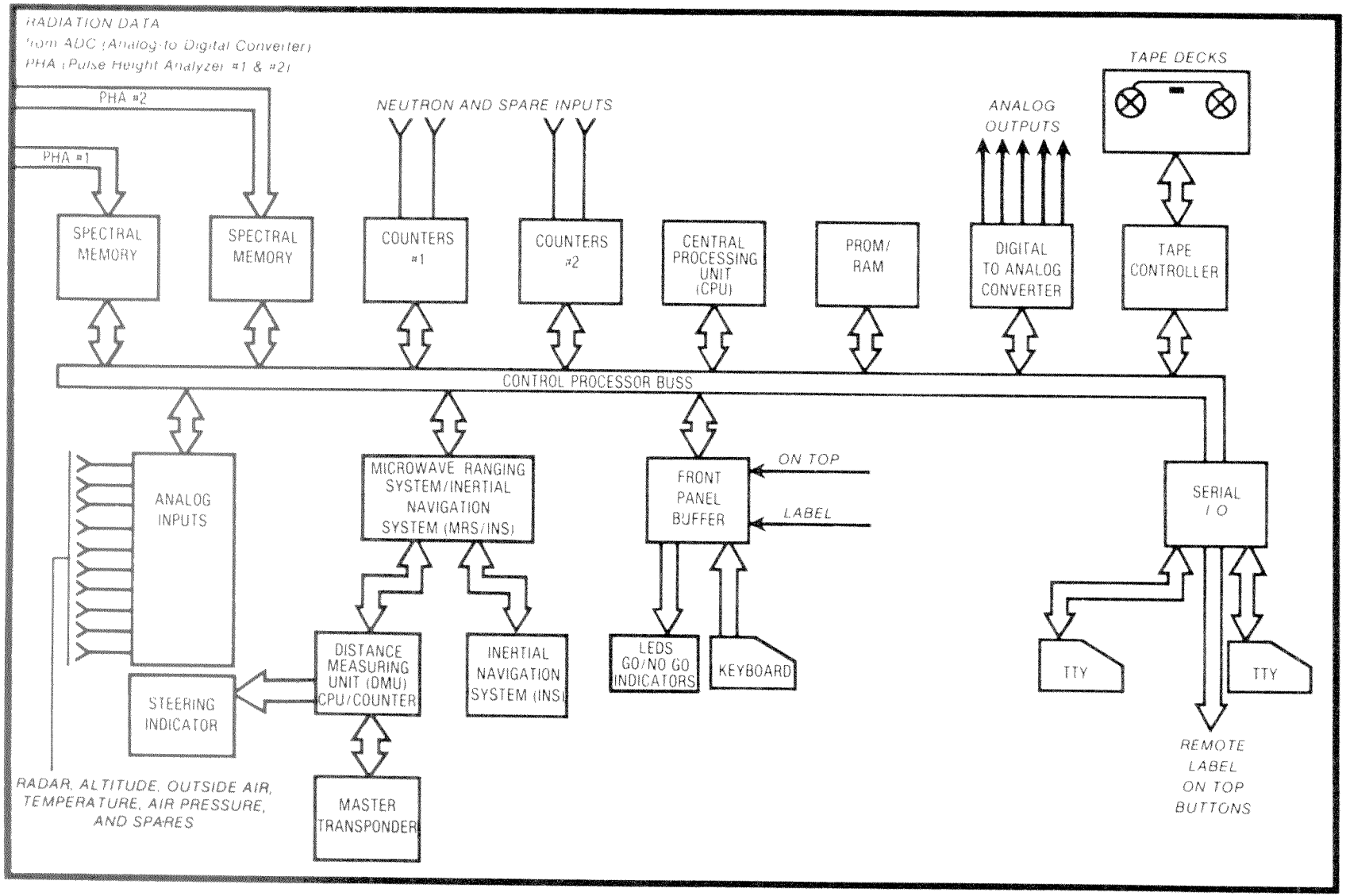

Figure 3. REDAR IV block diagram

APPENDIX D - RADIONUCLIDE REMOVAL BY WATER TREATMENT

The following tables show the percentages of radionuclides removed by various water quality and treatment systems.[1] The water treatment methods presented here fall into two general categories: conventional treatment methods (Tables D-1 through D-7) and non-conventional treatment methods (Tables D-8 through D-10). Conventional treatment methods include: 1) coagulation and settling; 2) sand filtration; 3) lime-soda ash softening; and 4) ion exchange. One or more of the conventional treatment methods should be available at most water purification plants. Non-conventional treatments are those used in conjunction with conventional treatments include: 1) phosphate coagulation; 2) addition of metallic dusts; and 3) addition of clay materials.

TABLE D-1

Removal of Soluble Radioactivity by Chemical Coagulation[a]

Nuclide	Chemical Form	Chemical Group	Number of Tests	Activity Range Counts/min-ml	pH Range Initial	pH Range Final	Removal Average, %	Removal Range, %	Ref.	Coagulants Used	Coagulant Dose, mg/L
^{137}Cs-^{137m}Ba	Cl^-	IA	27	19-17,390	7.5-7.8	6.5-7.9	0.5	0-37	5	b	c
^{89}Sr	Cl^- or NO_3^-	IIA	54	281-25,950	7.7-7.9	7.5-8.0	3	0-15	5	b	c
^{89}Sr		IIA	12	--	--	--	38	5-58	6	d	
$^{89,90}Sr$		IIA	--	--	--	6.8-7.0	3	2-5	9	e	f
^{140}Ba-^{140}La	Cl^-	IIA IIIA	81	42-17,150	7.4-7.6	7.2-8.2	59	1-84	5	b	c
			54	42-5,520	7.4-7.6	6.6-7.9	44	19-59	5	b	c
			54	44-8,070	7.4-7.6	7.2-7.8	52	27-72	5	b	c
^{140}Ba-^{140}La	Cl^-	IIA IIIA	4	17,500-46,200	7.7-7.8	--	64	58-71	7	g	h
^{46}Sc	Cl^-	IIIA	27	163-24,300	7.2-7.8	6.4-7.8	89	62-98	5	b	c
			27	326-20,060	7.6	7.0-7.8	92	62-99+	5	b	c
			27	202-26,100	7.5-7.9	6.9-8.2	91	69-99+	5	b	c
^{91}Y	Cl^-	IIIA	54[i]	188-4,166	7.5-7.6	6.0-7.6	90	40-99	5	b	c
			81[i]	367-20,860	8.1	7.8-10.2	92	56-99+	5	b	c
			81[i]	202-21,450	7.8-8.0	7.6-8.4	86	49-99	5	b	c
			81[j]	406-21,500	7.8	4.5-9.1	75	1-98	5	b	c
			81[j]	222-21,500	7.1-8.4	7.4-9.5	73	33.98	5	b	c
^{95}Zr-^{95}Nb	Oxylate complex	IVB VB	54	186-27,200	7.4-7.6	6.4-7.9	80	2-99	5	b	c
^{95}Zr-^{95}Nb	Oxylate complex	IVB VB	4	29,800-78,000	8.5-8.7	--	88	76-99	7	g	k
^{32}P	PO_4^{-3}	VA	27	228-17,625	7.6	6.4-7.8	96	68-99+	5	b	c
^{32}P	PO_4^{-3}	VA	12	--	--	--	97	68-99+	5	b	c
^{51}Cr	Cl^-, metal	VIB	54	5-758	6.7-7.3	5.3-7.8	9	0-60	5	b	c
^{99}Mo	MoO_3	VIB	54	84-10,085	7.6	7.0-8.2	10	0-60	5	b	c
^{185}W	Tungstate	VIB	54	233-28,290	7.5-7.9	6.6-8.4	46	1-96	5	b	c
			81	198-22,490	8.0-8.1	7.5-8.4	36	4-91	5	b	c

TABLE D-1 (Cont'd)

Removal of Soluble Radioactivity by Chemical Coagulation[a]

Nuclide	Chemical Form	Chemical Group	Number of Tests	Activity Range Counts/min-ml	pH Range		Removal		Ref.	Coagulants Used	Coagulant Dose, mg/L
					Initial	Final	Average, %	Range, %			
^{186}Re	Metal	VIIB	54	95-14,230	7.6	7.2-8.0	6	0-29	5	b	c
^{131}I	Iodide	VIIA	27	239-25,060	7.6	7.2-7.8	20	0-44	5	b	c
^{131}I	Iodide	VIIA	12	--	--	--	3.9	0-12	5	b	c
^{131}I	Iodide	VIIA	4	13,000-24,800	6.3-7.7	--	42	26-63	7	g	l
^{131}I	Iodide	VIIA	19	2,000[m]	--	5.4-7.6	0.8	0-10	8	n	
^{103}Ru	Cl^-	VIII	27	196-24,960	7.3-7.6	6.9-8.2	77	43-96	5	o	c
^{60}Co	Cl^-	VIII	2	24,900-49,400	7.6-8.2	--	16	8-23	7	g	h
^{142}Pr	Pr_2O_3	La series	27	102-12,050	7.2	7.4-8.0	96	83-99+	5	o	c
^{144}Ce-^{144}Pr	Cl^-	La series	27	244-20,510	7.4-7.6	7.2-8.4	91	28-99+	5	o	c
$^{141,144}Ce$-^{144}Pr	Cl^-	La series	4	41,000-55,800	7.1-7.6	--	98	96-99+	7	g	l
^{147}Pm	Cl^-	La series	27	136-19,040	7.4-7.6	7.0-8.2	87	4-99+	5	o	c
^{153}Sm	Sm_2O_3	La series	54	148-20,087	7.4-7.6	5.8-8.0	91	44-99+	5	o	c

TABLE D-1 (Cont'd)

Nuclide	Chemical Form	Chemical Group	Number of Tests	Activity Range Counts/min-ml	pH Range Initial	pH Range Final	Removal Average, %	Removal Range, %	Ref.	Coagulants Used	Coagulant Dose, mg/L
Fission Product mixture	Ba 5% Ce 27 Cs 1 Ru 3 Sr 17 TRE 4 Other 3		1	22,200	8.5	--	89	--	7	o	q
Fission Product mixture	Ba 5% Ce 59 Cs 50 Ru 16 Sr 10 TRE 10 Other 4		1	22,200	8.5	--	55	51-59	7	p	r

a Taken from Appendix D, reference 1
b $Al_2(SO_4)_3, FeCl_3, FeSO_4.7H_2O$
c 17.1, 34.2, and 103
d Variable amounts of clay added
e Alum, $Fe_2(SO_4)_3$ and other treatments
f 10 as Fe and as Al
g $CaCO_3$ and $FeCl_3$ or alum
h 50-100
i $Ca(OH)_2$ used as alkaline agent
j Na_2CO_3 used as alkaline agent
k 40-400
l 50-200
m μCi/ml
n Variety of Chemicals
o $Al_2(SO_4)_3, FeCl_3$, or alum
p $FeCl_3 + CaCO_3$
q 170-240
r 100-400

REFERENCES:

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TABLE D-2

Coagulation and Settling Results (Jar-Test Studies)[a]

Nuclide	Clay added[b] (mg/L)	Coagulant added[c] (g/gal)	Final pH	Removal %
^{137}Cs-^{137m}Ba	0	1		0-6
	100	1		35-65
^{89}Sr	0	1.5[d]	6.7-7.8	0-6
	100	0.5-6	6.7-10.7	0-51
^{115}Cd	0	1		40-60
	100	1-5		60-95
^{140}Ba-^{140}La	100	1-6	7.5-8.2	28-84
^{46}Sc	100	1-6	6.5-8.2	66-98
^{91}Y	0	1.5[d]	6.8-7.1	83-93
	100	1-6	7.0-10.2	34-99
^{95}Sr-^{95}Nb	0	1-5		70-98
	100	1		95-99
^{32}P	100	0.5-1.5[d]	6.8-8.8	97-99
^{51}Cr	100	1-6	7.6-8.8	73-98
^{185}W	100	1-6	7.5-8.4	5-91
^{131}I	100	0.5-2[d]	6.9-9.0	0-10
^{144}Ce	0	1-1.5[d]	7.2-7.8	81-94
	100	0.5-2.5[d]	7.0-7.8	85-96

[a] Taken from Appendix D, reference 1.
[b] Local clay was added.
[c] Coagulant includes alum, ferrous sulfate or ferric chloride, lime, soda ash, or sodium hydroxide, and sodium silicate.
[d] No sodium silicate added. Where added, sodium silicate equals 40 percent primary coagulant dose.

TABLE D-3

Removal of ^{131}I by Auxiliary Processes[a]

	Dosage (mg/L)			Final Characteristics (mg/L)[b]			Removals (%)	
Turbidity	Alum	NaOH	Auxiliary Chemical	pH	Alkalinity	Turbidity	Coagulation and Settling	Coagulation Settling and Centrifuging
103	25.7	38.9	5-15[c]	5.8-7.1	17-68	0-15	64-72	74-78
103	25.7	38.9	3.5[d]	7.1	65	0	38	56
17.3-274	25.7	38.9	0.12-3.8[e]	5.8-7.5	19-74	1-40	42-74	48-76
	113.5		0.013-0.13[e]	6.0-6.9			55-90	
	247		0.13-1.1[e]	6.3			90-92	
	100.64[f]		0.13[d]	6.3			95.5	

a Taken from Appendix D, Reference 1.
b Except for pH.
c Auxiliary chemical was activated carbon.
d Auxiliary chemical was copper sulfate.
e Auxiliary chemical was silver nitrate.
f Either 20 mg/L as iron or 100.64 mg/L as $Fe_2(SO_4)_3\ 9H_2O$.

TABLE D-4

Removal of Mixed Fission-Product Isotopes by Coagulation and Settling[a]

Mixture	Removal (%)
Fission-product mixture 1[b]	61-84[c]
Fission-product mixture 3[d]	46
Fission-product mixture 4[e]	89
Fission-product mixture 5[f]	51-59

[a] Taken from Appendix D, Reference 1.
[b] Iodine dissolver solution.
[c] Clay also added.
[d] Three-year-old fission-product mixture.
[e] Iodine dissolver solution aged 30 days.
[f] Mixed fission-product waste containing ^{137}Cs-^{137m}Ba, and ^{106}Ru-^{106}Rh.

TABLE D-5

Laboratory Sand-Filtration Results[a]

Nuclide	Initial Activity counts/min-mL	Volume passed mL	pH of Effluent	Removal (%) Range	Removal (%) Average
^{137}Cs-^{137m}Ba	800	500	8.3	10-70	50
^{89}Sr	2,700	750	8.3	1-13	4
^{115}Cd	1,200	500	8.1	60-99	95
^{140}Ba-^{140}La	1,300	750	7.6	39-99	74
^{46}Sc	1,500	750	8.3	94-99	96
^{91}Y	5,700	750	7.0	84-89	87
^{95}Zr-^{95}Nb	3,400	500	7.8	91-96	93
^{185}W	2,200	750	7.1	3-18	8

[a] Taken from Appendix D, Reference 1.

TABLE D-6

Results of Lime-Soda Ash Treatment for Removal of Strontium[a]

Treatment	Removal of Activity (%)
Stoichiometeric	75.0
Excess lime-soda ash, 20 mg/L	77.0
Excess lime-soda ash, 50 mg/L	80.1
Excess lime-soda ash, 100 mg/L	85.3
Excess lime-soda ash, 150 mg/L	97.3
Excess lime-soda ash, 200 mg/L	99.4
Excess lime-soda ash, 300 mg/L	99.7

[a]Taken from Appendix D, Reference 1.

TABLE D-7

Efficiency of Ion-Exchange Materials in Removing Individual Nuclides[a]

	Removal (%)			
Nuclide	Cation Exchange	Anion Exchange	Mixed Bed	Greensand
^{185}W	12-16	97.2-99.2	98.2	9
^{91}Y	86-93.1	94.2-98.5	97.6-98.7	75
^{46}Sc	95.7-97.2	98.8-99.0	98.5-98.7	96.4
^{89}Sr	99.1-99.8	5-7	99.95-99.97	99.8
^{140}Ba-^{140}La	98.3-99.0	36-42	99.5-99.6	96.3
^{137}Cs-^{137m}Ba	99.8	9	99.8	
^{115}Cd	98.5	0	99.2	
^{95}Zr-^{95}Nb	58-75	96.4-99.9	90.9-99.4	

[a]Taken from Appendix D, Reference 1.

TABLE D-8

Removal of Radionuclides by Phosphate Coagulation[a]

Nuclide	Coagulant	Coagulant Dose (mg/L)	Removal (%)
^{144}Ce	KH_2PO_4	200	99.8
	Na_3PO_4	120	99.9
^{89}Sr	KH_2PO_4	100	81.3
	Na_3PO_4	240	97.8
^{91}Y	KH_2PO_4	100	99.9
^{124}Sb	KH_2PO_4	100	66.1
	Na_3PO_4	120	67.4
^{65}Zn	KH_2PO_4	50	99.6
^{185}W	KH_2PO_4	200	10.7
^{95}Zr	KH_2PO_4	100	99.5
^{95}Nb	KH_2PO_4	100	99.2

[a] Taken from Appendix D, Reference 1.

TABLE D-9

Removal of Radioactive Contaminants by Metallic Dusts (Metal Dust, 1,000 mg/L, 90-min Contact Time, Filtered Sample Counted)[a]

Contaminant	Stock Solution (pH)	Initial Activity (counts/min-mL)	Removal (%)			
			Iron[b]	Zinc	Copper	Aluminum
^{106}Ru-^{106}Rh	8.0-8.2	1,975- 3,950	99.6	98.4	93.7	98.2
^{91}Y	7.9-8.0	1,610- 3,230	98.0	98.0		
^{95}Zr-^{95}Nb	7.2-8.3	1,210- 4,470	99.1	97.9	99.1	99.8
^{32}P	7.8-8.4	128-12,000	99.8	98.1		
^{131}I	6.5-8.2	4,288- 6,689	37.2	45.7	42.2	23.2
$^{141,144}Cd$-^{144}Pr	7.9-8.1	3,915- 4,491	99.9	99.9	99.5	99.8
^{140}Ba	7.9-8.2	4,644-10,205	94.8	74.5	65.7	73.8
^{60}Co	8.0-8.2	1,571- 4,792	92.2[c,d]		47.8	30.2[b]
^{137}Cs-^{137m}Ba	8.0	13,085	8.6			
FPM-5[e]	2.0-7.2	2,890- 4,220	55.5	39.6	49.3	8.2
FPM-6[f]	7.2-8.0	4,730-10,375	85.8	76.6	92.1	89.4

a Taken from Appendix D, Reference 1.
b Iron samples were centrifuged before counting.
c Metal dust, 500 mg/L.
d Sixty-minute contact.
e FPM-5, mixed fission-product waste containing mainly ^{137}Cs-^{137m}Ba and ^{106}Ru-^{106}Rh.
f FPM-6, iodine dissolver solutoin aged 20 days.

TABLE D-10

Effect of Added Clay on Removal of Radionuclides[a,b]

Radionuclide	100 mg/L	750 mg/L	5,000 mg/L
^{140}Ba-^{140}La	41	58	85
^{115}Cd	3	30	64
^{144}Ce-^{144}Pr	70-80	86	99+
^{137}Cs-^{137m}Ba	38	87	98.0
^{46}Sc	53	91.7	96.9
^{89}Sr	2-12	14-22	49-52
^{185}W	0	4	49
^{91}Y	22-45	56-70	93.6
^{95}Zr-^{95}Nb	93.5	99.0	98.0
^{32}P			78-82
^{131}I			9-20
^{60}Co			85-99+

[a] Taken from Appendix D, Reference 1.
[b] Local clay added to produce turbidity.

APPENDIX D - REFERENCE

1. The American Water Works Association, Inc., Water Quality and Treatment A Handbook of Public Water Supplies, Third Edition (1971).

APPENDIX E - DETERMINING THE MINIMUM DETECTABLE LEVEL OF ACTIVITY

1. METHOD OF CALCULATING THE MINIMUM DETECTABLE LEVEL OF ACTIVITY

Brand name instruments mentioned 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 for use.

The Minimum Detectable Level (MDL) of activity is the level of activity that can be distinguished from background. MDL varies for every detection system; it also varies with background activity and must be calculated when measurements are made. The MDL, shown in Table 9 of the text and Table E-1 of this appendix, for each of the detectors is based on two standard deviations (2 sigma) of the background count rate. The instrument (ratemeter) time constant affects the standard deviation by:

$$S = \left(\frac{a}{2RC}\right)^{1/2}$$

where S = standard deviation, sigma
a = single background reading, cps
RC = instrument time constant, seconds

For the Victoreen Model 489-4 GM detector and the Victoreen Thyac III ratemeter where the background countrate is 75 cpm (see Table E-2), the MDL is:

$$S = \left(\frac{75/60}{2 \times 15}\right)^{1/2} = 0.20 \text{ cps}$$

$$2S = 2 \times 0.20 \times 60 = 24 \text{ cpm}$$

the MDL in μCi/L of a specific radionuclide is calculated from the countrate MDL and a calibration using a sample of known concentration for the specific radionuclide.[1]

TABLE E-1

Calculation of MDL in μCi/L I-131
in a 12" x 9" x 10" Jerri Can for Four Instrument Systems

Instrument	Minimum Detectable Countrate (cpm)	Efficiency Factor (cpm/μCi/L)	Minimum Detectable Level (μCi/L)
Thyac III 489-55 1.25"x1.5" NaI(Tl)	215	284,000	7.57×10^{-4}
Thyac III 491-30 (GM)	28	470	0.053
Thyac III 489-4 (GM)	24	670	0.037
CDV-700 with shielded Victoreen 6306[a]	40	1523	0.026

[a] Values are the average of seven instrument systems.

TABLE E-2

MDL in Counts per Minute for Four Instrument Systems

Meter	Probe	Background (cpm)	Standard Deviation (cpm)	Minimum Detectable Countrate (cpm)
Thyac III No. 4552	489-55 1.25"x1.5" (NaI) No. 1270	5800	108	216
	491-30 (GM) No. 2400	60	11	22
	489-4 (GM) No. 4155	100	14	28
Thyac III No. 4559	489-55 1.25"x1.5" (NaI) No. 1271	5800	108	216
	491-30 (GM) No. 2404	100	14	28
	489-4 (GM) No. 4183	75	12	24
CDV-700	shielded Victoreen 6306	79[a]	20	40

[a] Average of seven instruments.

MDLs for all counting techniques discussed in Section 4.1.1 of this document are calculated in the same way. The MDL in μCi/L for I-131 is calculated below. Assuming the background count rate, from Table E-2, for the Model 489-4 GM probe (75 cpm) has not changed, the count rate MDL is 24 cpm. The efficiency factor (average of two systems) for the immersion technique is 670 cpm/μCi/L of I-131 (see Table E-3). The MDL is therefore:

$$\text{MDL} = \frac{24 \text{ cpm}}{670 \text{ cpm}/\mu\text{Ci/L I-131}} = 0.037 \ \mu\text{Ci/L of I-131.}$$

In the immersion technique and the ion exchange method, the MDL depends on the background count rate. The values cited in the above example calculation may not be applicable in a real emergency, particularly in the EPZ. If the accident is severe enough to deposit sufficient activity on vegetation to cause I-131 levels in milk to approach the preventive response levels, the background activity level will be elevated. The elevated background levels will increase the MDL for all monitoring methods. When either method is used for accident monitoring, real time background count rates must be determined and corresponding MDLs calculated.

2. DETERMINATION OF I-131 COUNTING EFFICIENCIES AND MDLs FOR FOUR INSTRUMENT SYSTEMS

Counting efficiencies in counts pre minute per microcurie per liter for I-131 were determined for four instrument systems:

1) Two Thyac III 490 ratemeters with Victoreen 489-55 1.5 x 1.25 inch NaI(Tl) probes.

2) Two Thyac III 490 ratemeters with Victoreen 491-30 GM probes.

3) Two Victoreen Thyac III 490 ratemeters with Victoreen 489-4 GM probes.

TABLE E-3

Immersion Methods, Calculation of
cpm/μCi/L I-131 for Four Instrument Systems

Instrument	Probe	Background (cpm)	Gross (cpm)	Net (cpm)	cpm/μCi/L I-131
Thyac III[a] No. 4552	489-55 1.25"x1.5" (NaI) No. 1270	5,800	375,000	369,000	315,555
	491-30 (GM) No. 2400	60	600	540	461
	489-4 (GM) No. 4155	100	650	550	470
Thyac III[a] No.4559	489-55 1.25"x1.5" (NaI) No.1271	5,800	300,000	294,200	251,453
	491-30 (GM) No. 2404	100	650	550	470
	489-4 (GM) No.4183	75	1,100	1,025	876
CDV-700	6306				
	1)	85	1,600	1,515	1,317
	2)	80	2,000	1,920	1,641
	3)	80	1,700	1,620	1,385
	4)	70	1,800	1,730	1,479
	5)	65	2,000	1,935	1,654
	6)	85	2,200	2,115	1,808
	7)	90	1,700	1,610	1,376

[a] Meter readings are 10% of full scale.

4) Seven CDV-700 ratemeters with Victoreen 6306 bismuth loaded GM probes with 0.127 cm lead + 0.08 cm copper shields.

The geometry for determining the efficiency was a 5 gallon "Jerri Can" with the dimensions 12" in length x 9" in width x 10" in height (see Figure E-1).

In order to determine counting efficiences and MDLs, sufficient activity must be present in the sample to produce an instrument meter reading several times the background count rate (i.e., typically midrange of the selected meter scale). For the above geometry, the procedure used called for placing 20 liters of water in the "Jerri Can" and mixing with approximately 24.0 μCi of I-131. The resulting concentration in the container was approximately 1.2 μCi per liter. An acrylic tube (1/8 inch thick wall) sealed on the bottom to prevent liquid from reaching the probe was centered in the container. Each detector probe was introduced in turn and the count rate recorded. The results are presented in Table E-3. After mixing the 24.0 μCi aliquot and after the count rate determination, samples were collected for laboratory analysis to determine the concentration of I-131 in the 20 liters.

Minimum detectable levels (MDLs) of activity for I-131 in 20 liters of liquid were also determined for the four instrument systems (Table E-2). Averages of MDLs in counts pre minute were used to determine MDLs in μCi per liter as presented in the main report and in Table E-1.

Further laboratory experiments utilizing I-131 concentrations near the preventive response level, 0.015 μCi per liter, confirm the MDLs presented in Table E-1. Of the instruments used, only the Thyac III 490 ratemeter with the Victoreen 489-55 NaI(Tl) detector is sensitive enough to detect I-131 at the preventive response level using the immersion counting method.

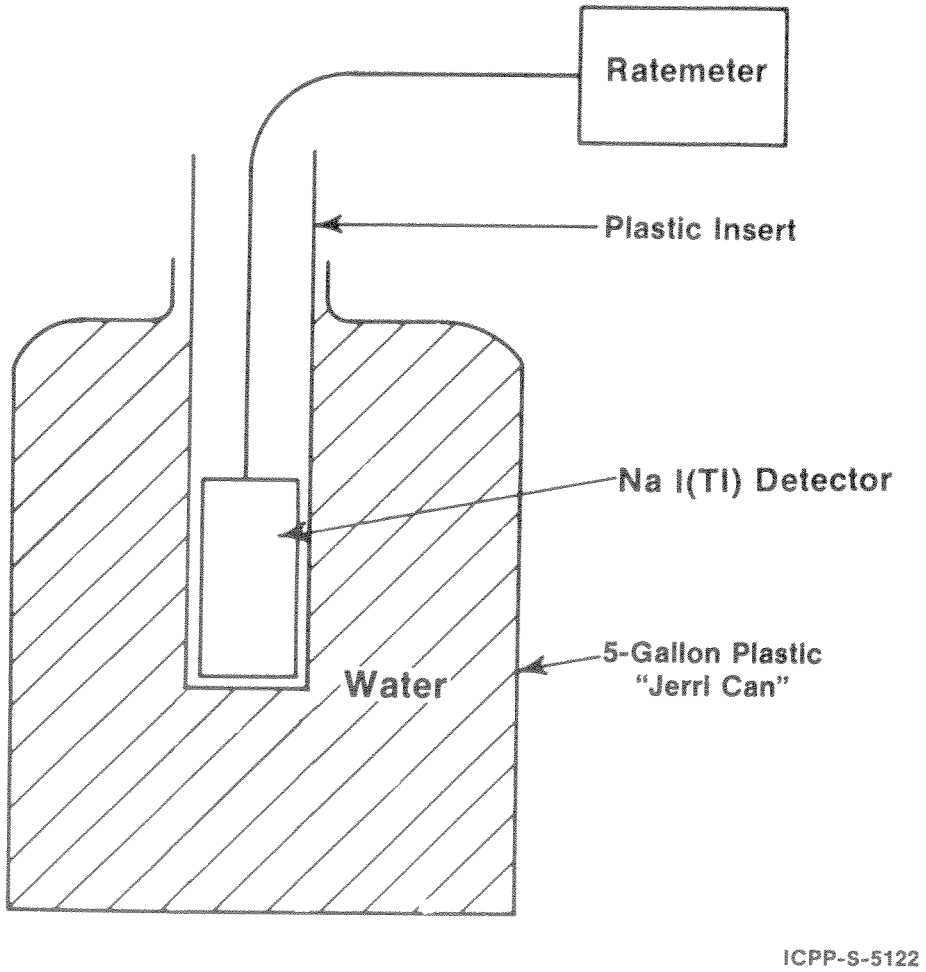

Figure E-1. Schematic Diagram of the Immersion Technique for Water Monitoring

3. ESTIMATION OF VEGETATION CONTAMINATION LEVELS BY USING GM DETECTORS

Open window energy response comparisons were made over the range of 0.356 to 1.25 Mev for two types of GM detectors. One detector, a Victoreen Model 489-4, having a wall thickness of 30 mg/cm^2 and the second detector, a pan cake type Eberline Model HP-260, having a window thickness of 1.4 to 2.0 mg/cm^2. The results of these comparisons are presented in Table E-4. Ba-133 was used to simulate the I-131 energy. The relative responses, e.g., ratio of the 1.4 to 2.0 mg/cm^2 pancake detector to the 30 mg/cm^3 detector, were 1, 3, and 1.3 for Ba-133, Cs-137, and Co-60, respectively.

Vegetation contamination levels can be estimated from ground survey measurements and the following equations and factors[2]:

$$D = R \times F$$

where: D = ground deposition in $\mu Ci/m^2$

R = GM meter reading in units of 100 counts/min (background corrected)

F = factor from Table E-5.

The above equation is also based on the following assumptions:

1. A portable GM survey-meter calibrated to yield 3000 to 4000 counts/minute per mR/hour of radium gamma is used.
2. The detector probe is held at not more than 5 cm above the ground with the beta-shield open.
3. 100 counts/minute can be detected above a normal 50 to 100 counts/minute background.
4. Readings are taken in open terrain not in close proximity to heavy vegetation cover or buildings.

TABLE E-4

Open Window Energy Response Comparison for Two GM Detector Instruments

Source	Victoreen Thyac III Model 490 Ratemeter SS No. 4559M with a Victoreen Model 489-4 GM detector[a] Counting Yield (cpm/μCi)	Ludlum Model 2A Ratemeter SS No. 13873 with an Eberline Model HP-260 GM detector[b] Counting Yield (cpm/μCi)	Source to Detector Distance (inches)	Relative Response (HP-260/489-4)
Ba-133	304.3	316.3	3	1.04
Cs-137	1329.7	4009.3	3	3.02
Co-60	857.6	1231.3	3	1.44
Ba-133	22.7	21.8	12	0.96
Cs-137	60.9	187.4	12	3.08
Co-60	80.2	96.2	12	1.20

a Victoreen Model 489-4 detector wall thickness is 30 mg/cm^2.

b Eberline Model HP-260 detector window thickness is 1.4-2.0 mg/cm^2.

TABLE E-5

Ground Surface Contamination Levels[a]
of Various Nuclides Required to Yield
100 counts/min (Net) on a GM Meter (Open Window)[b]

Nuclide	F ($\mu Ci/m^2$ per 100 counts/min)
$^{95}Zr + ^{95}Nb$	6
^{141}Ce	2
^{131}I, ^{103m}Ru, mixed Ru-Rh (100 d old)[c]	1
^{60}Co, ^{89}Sr, ^{90}Sr, ^{90}Y, ^{91}Y, ^{137}Cs, ^{140}Ba, ^{140}La $^{144}Ce + ^{144}Pr$, $^{106}Ru + ^{106}Rh$, mixed radioiodines (1 h to 1 week old), mixed fission-products (100 d old)	0.3

[a]Level varies with background readings, ground roughness and vegetation cover.

[b]Taken from Environmental Monitoring in Emergency Situations, IAEA Safety Series Report No. 18, Vienna (1966).

[c]Age refers to time since irradiation of the fuel from which the fission products were released.

By substituting the minimum detectable countrate (24 cpm for the Victoreen 489-4 and 26 cpm for the Eberline HP-260) for the instrument systems into the above equation, a surface area MDL maybe estimated. For example, the factor (F) from Table E-5 is 0.3 for most fresh fission-products; therefore, the MDL for I-131 using the Victoreen 489-4 detector is:

$$MDL = (0.24)(0.3) = 0.072\ \mu Ci/m^2$$

or for the Eberline HP-260 detector the MDL is:

$$MDL = (0.26)(0.3) = 0.078\ \mu Ci/m^2$$

Since the Eberline HP-260 detector is a factor of 3 more sensitive than the Victoreen 489-4 at the Cs-137 energy, its MDL for Cs-137 will be somewhat lower (e.g., MDL = $(0.26)(0.1) = 0.026\ \mu Ci/m^2$). Tables 9 and 10 contain the derived preventive response levels for surface contamination on vegetation. By comparing these derived values for I-131 and Cs-137 to the above MDL's it can be readily determined that both GM instrument systems are sensitive enough for monitoring both radionuclides on leafy vegetables. However, neither system appears to have the required sensitivity for monitoring I-131 on produce when the child is considered the critical segment of the population. Also, when long-term ingestion (Table 9) is considered, neither system appears to have the required sensitivity for monitoring Cs-137 on produce when either the child or the teenager is considered the critical segment of the population.

A second field evaluation method of estimating leafy vegetation contamination levels is described in the following stepwise procedure:[2]

1. Cut enough vegetation to fill a 30 cm x 40 cm plastic bag about half full. This represents about one-half of a kilogram wet weight. The vegetation should be collected from at least 1 m^2 of ground and should be cut at 1-2 cm above the ground level. Care should be taken to prevent the cut material from being contaminated with soil.
2. Compress the air out of the bag and seal the end.
3. Move to a low background area.

4. Flatten the plastic bag and lay the probe of a portable GM survey-meter on the center of the bag.
5. Fold the bag over the GM probe and note the reading (window open and background corrected).
6. Calculate the vegetation contamination level from the following equation:

$$C = R/K$$

where: C = vegetation concentration in μCi/kg,
R = GM meter reading in units of 10^2 X counts/min (background corrected),
K = 10^2 X counts/min per μCi/kg as given in Table E-6.

TABLE E-6

Typical GM Survey-Meter Readings
Probe Inserted in the Center of a Large
Sample of Vegetation[a]

Nuclide	K (10^2 X counts/min per μCi/kg)
^{89}Sr, ^{90}Sr + ^{90}Y	20
^{106}Ru + ^{106}Rh	50
^{140}Ba + ^{140}La	10
^{131}I + ^{137}Cs	4

[a]Taken from Environmental Monitoring in Emergency Situations, IAEA Safety Series Report NO. 18, Vienna (1966).

APPENDIX E - REFERENCES

1. C. Distenfeld and J. Klemish, Environmental Radioiodine Monitoring to Control Exposure Expected from Containment Release Accidents, NUREG/CR-0315, (December 1978), pp 23-24.

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

APPENDIX F - FIELD SAMPLING AND SAMPLE PRESERVATION METHODS

1. INTRODUCTION

Field radiation surveys are of value for the rapid determination of the extent of dispersal of radioactive contamination on vegetation, on the ground, or in surface water. Although the presence of radioactivity can be detected without sampling, for any quantitative assessment of the amount of radioactivity present, sampling is necessary. The collection of environmental samples should be concurrent with the gross radiation survey measurements which are made in the field. The sample collection locations and the field radiation survey data can be related to quantitative analyses of the environmental samples. If a sufficient number of samples are collected, the quantitative data obtained from these samples may be used to develop a calibration curve. This calibration curve may be used with the gross field radiation survey data to estimate the quantity and identity of radioactive contamination in nearby areas where gross radiation surveys were made but actual samples were not collected. This procedure is necessary, since the potential number of environmental samples that could be collected for quantitative analysis during an emergency could soon overwhelm the available analytical laboratory capabilities.

2. VEGETATION SAMPLING AND PRESERVATION METHODS

Vegetation samples should be representative of the field area where the gross radiation surveys were made. The vegetation sample should be collected from a minimum ground surface area of one square meter.[1] Surface grown leafy vegetables should be cut at 1 to 2 cm above ground level and care should be taken to avoid contamination of the vegetation by soil. The sample size may vary from 0.5 to 4.0 kilograms[1,2] wet weight depending on the number of separate destructive analyses that are conducted and the level of contamination which may be expected (e.g., the 4 kilogram sample would be the size of samples which are approaching background concentration). Approximately 1 to 10 grams of ash are

required for each chemical separation and 40 grams of ash from the edible portions of a representative sample are required for radiochemical and gamma spectroscopic analyses. The 4 kilogram sample should be adequate to provide the 40 gram ash sample[2] and to assure good geometry during gamma isotopic analysis prior to ashing.[3]

No special techniques are required for the sampling of cereal grains, fruits and vegetables. However, before analysis, these samples should be treated in the same way as if they are being prepared for human consumption (e.g., washing, peeling, shelling, etc.).[1] No special preservatives are required other than refrigeration to prevent spoilage.

3. WATER SAMPLING AND PRESERVATION METHODS

The volume of water sample collected should be sufficient to perform all the required analyses plus an additional amount to provide for any quality control needs, split samples or repeat examinations.[4] Typically, a 3.5 liter sample volume will be adequate to conduct gamma spectroscopy and chemical analyses.[3,4] However, if duplicate analyses are to be conducted on the same sample, a 7-8 liter sample will be required for the laboratory analyses.[4] For preliminary field measurements utilizing the immersion method, a 20 liter sample volume will be required. The 3.5 or 8 liter aliquots could be taken from this 20 liter sample for laboratory analyses.

In rivers or streams, the water samples should be collected in the center of the channel at 0.4 to 0.6 of the total depth where the flow is turbulent, well mixed, and the settling of solids is minimal.[4] Sampling at 0.4 to 0.6 of the total depth will avoid skimming of the water surface or dragging the channel bottom, which avoids the problem of collecting debris which may have concentrated the radioactivity present in the water.

Two water sampling locations should be established on a stream which is receiving water from a contaminated source. One location, for background conditions, should be upstream of the point of inflow and one location

should be downstream. The downstream sampling location should not be closer to the point of inflow than 10 widths of the receiving stream.[3,4] This will allow for uniform mixing and dilution because of near field turbulence prior to reaching the downstream sampling location.

Care should be taken in selecting sample containers and preserving the water samples for laboratory analysis. Sample containers that minimize radionuclide losses by adsorption or other processes should be used during collection and storage. Teflon containers are preferred because of their resistance to adsorption. Polyethylene and polyvinyl chloride containers are also recommended. Glass and metal containers tend to retain radionuclides. Glass bottles also are more subject to breakage during handling.[4]

When adsorption problems persist, wash containers and sampling apparatus with HCl or HNO_3 before sampling or flush the containers and apparatus with the liquid to be collected before final sampling.

The standard preservation technique for radionuclides in water and waste water samples is acidification to a pH of <2 with HCl or HNO_3.[4,5] Several exceptions exist:

1. Tritium - add no acid; begin analysis immediately upon return to the laboratory.
2. Carbon 14 - see Tritium.
3. Radiocesiums - use HCl only.
4. Radioiodines - see Tritium: acid oxidizes iodides to iodines which are rapidly lost through volatilization. For samples containing ^{3}H, ^{14}C, or ^{131}I along with radionuclides requiring preservatives, obtain duplicate samples and add acid to only one.

Add acid preservative after sample collection (but not before filtration) or as soon as practicable but do not delay beyond five days.

When acid preservation is not desirable: 1) add stable isotopic carriers of the same elements as the radionuclides; and 2) refrigerate samples at or near their freezing temperature to retard chemical reaction rates and to inhibit bacterial growth.

APPENDIX F - REFERENCES

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

2. Department of Energy, A Guide for Environmental Radiological Surveillance at ERDA Installations, ERDA 77-24 (1977).

3. U.S. Environmental Protection Agency, Environmental Radioactivity Surveillance Guide, ORP-SID-72-2 (1972).

4. U.S. Environmental Protection Agency, Handbook for Sampling and Sample Preservation of Water and Wastewater, EPA-600/4-82-029 (September 1982).

5. Standard Methods for the Examination of Water and Wastewater, 15th Edition, APHA-AWWA-WPCF (1980).

APPENDIX G - GLOSSARY

AMS	Aerial Measuring System - DOE operated aerial radiation surveillance program which may be used for plume verification and ground deposition monitoring.
ARAC	Atmospheric Release Advisory Capability - Atmospheric computer modeling system based at Lawrence Livermore National Laboratory - can be utilized for making dose projections.
Deposition Velocity	A calculated rate (m/sec) at which airborne species (i.e., particulates or gases) are impacted upon a depositional surface. The calculations are based upon measurements of air concentrations and surface area concentrations.
Derived Response Level	A calculated radionuclide concentration in foodstuffs, milk, and water, which, if ingested without any protective actions, would result in a projected dose commitment equivalent to the preventive or emergency PAGs.
ECCS	Emergency Core Cooling System
Emergency PAG	Applies to incidents where protective actions of great impact on the food supply are justified because of the projected health hazards. An emergency PAG establishes a dose commitment level at which responsible officials should isolate food containing radioactivity to prevent its introduction into commerce, and at which the responsible officials must determine whether condemnation or another disposition is

Emergency PAG (contd)	appropriate. (Equivalent to a projected dose commitment of 15 rem thyroid, 5 rem whole body or bone marrow to an infant or adult.)
Emergency Response Level	The concentration of radionuclides in foodstuffs, milk, or water which if ingested would, without any protective action, result in a projected dose commitment equivalent to the emergency PAG.
EOF	Emergency Operations Facility - A licensee controlled and operated offsite support center with facilities for coordination of emergency response activities with Federal, State, and local agencies and management of overall licensee emergency response.
EOC	Emergency Operations Center - The center from which emergency response teams receive their field directions. Usually operated and staffed by State or local personnel.
EPZ	Emergency Planning Zone - A generic area defined about a nuclear facility to facilitate emergency planning. It is defined for the plume (0-10 mile radius) and ingestion (0-50 mile radius) exposure pathways. In relation to emergency response, an EPZ is an area in which best effort is performed making use of existing emergency plans and is not an area in which particular criteria must be met.
FRC	Federal Radiation Council

FRERP	Federal Radiological Emergency Response Plan - The single Federal plan for coordinating significant Federal response to any civil radiological emergency. 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.
FRMAP	Federal Radiological Monitoring and Assessment Plan
FRPCC	Federal Radiological Preparedness Coordinating Committee - Consists of the Federal Emergency Management Agency (FEMA) which chairs the Committee, Nuclear Regulatory Commission (NRC), Environmental Protection Agency (EPA), Department of Health and Human Services (HHS), Department of Energy (DOE), Department of Transportation (DOT), Department of Defense (DOD), United States Department of Agriculture (USDA), Department of Commerce (DOC) and, where appropriate and on an ad hoc basis, other Federal departments and agencies.
Government Agencies	Federal - agencies, departments or their components of the U.S. Federal government, having a role in emergency planning and preparedness. State - government agency or office having the principal or lead role in emergency planning and preparedness. Local - government agency or office having the principal or lead role in emergency planning and preparedness. Generally this will be the county government.

Ingestion Exposure Pathway	The principal exposure from this pathway would be from ingestion of contaminated water or foods such as milk or fresh vegetables. The time of potential exposure could range in length from hours to months. The radial distance affected is approximately 50 miles.
LOCA	Loss of Coolant Accident
Milk Shed	All dairy farm areas supplying milk for a given city or geographic marketing region.
PAG	Protective Action Guide - the projected dose commitment values to individuals in the general population that warrant protective action following a release of radioactive material.
Preventive PAG	Applies to situation where protective actions causing minimal impact on the food supply are appropriate. A preventive PAG establishes a dose commitment level at which responsible officials should take protective action to prevent or reduce the concentration of radioactivity in food or animal feed. (Equivalent to a projected dose commitment of 1.5 rem thyroid, 0.5 rem whole body or red bone marrow to an infant.)
Preventive Response Level	The concentration of a radionuclide in foodstuffs, milk, or water which if ingested, without any preventive action, would result in a projected dose commitment equivalent to the preventive PAG.

Projected Dose Commitment	The dose commitment that would be received in the future by individuals in the population group from a contaminating event if no protective action were taken (rem is the unit of measurement).
Protective Action	An action taken to avoid or reduce the projected dose commitment. (Sometimes referred to as protective measure.)
RSS	Reactor Safety Study (WASH-1400).
Source Term	The amount of activity and chemical forms of radionuclides released from a nuclear power plant, often a function of time.