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ENVIRONMENTAL RADIOACTIVITY SURVEILLANCE GUIDE

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Radiation Programs

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U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS
SURVEILLANCE AND INSPECTION DIVISION
WASHINGTON, D.C. 20460

FOREWORD

The Office of Radiation Programs carries out a national program designed to evaluate the exposure of man to ionizing and nonionizing radiation, and to promote development of controls necessary to protect the public health and safety and assure environmental quality.

Within the Office of Radiation Programs, the Surveillance and Inspection Division conducts programs relating to sources and levels of environmental radioactivity and the resulting population radiation dose. Reports of the findings are published in the monthly publication, *Radiation Data and Reports*, appropriate scientific journals, and Division technical reports.

The technical reports of the Surveillance and Inspection Division allow comprehensive and rapid publishing of the results of intramural and contract projects. The reports are distributed to State and local radiological health programs, Office of Radiation Programs technical and advisory committees, universities, libraries and information services, industry, hospitals, laboratories, schools, the press, and other interested groups and individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage readers of these reports to inform the Office of Radiation Programs of any omissions or errors. Your additional comments or requests for further information are also solicited.

W. D. ROWE
Deputy Assistant Administrator
for Radiation Programs

PREFACE

Discharges of radioactivity to the environment from nuclear power stations contribute to the radiation dose received by the general population. The Surveillance and Inspection Division developed this "Environmental Radioactivity Surveillance Guide" as a part of its responsibility to provide guidance for surveillance of nuclear facilities. The Guide recommends methods for conducting a minimum level of environmental radiation surveillance outside the plant site boundary of light-water-cooled nuclear power facilities but does not establish requirements for any particular organization for conducting the surveillance program.

During the period that the Guide was being developed, the Division consulted with the Atomic Industrial Forum, members of industry, the Atomic Energy Commission, and other colleagues in the Environmental Protection Agency on the technical contents of the Guide. A substantial number of comments and recommendations from these groups were included in the Guide. In addition, the contents of the Guide were discussed in a presentation before the Conference of State Radiation Control Program Directors in May 1972. Members of the Conference submitted their comments and recommendations, and these were incorporated into the Guide. The Surveillance and Inspection Division is grateful to the members of these organizations and agencies for the time and effort they spent in reviewing and commenting on the content of the Guide.

Charles L. Weaver

CHARLES L. WEAVER
Acting Director
Surveillance and Inspection Division

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CHAPTER 1

Introduction

This Environmental Radioactivity Surveillance Guide recommends methods for conducting a minimum level of environmental radiation surveillance outside the plant site boundary of light-water-cooled nuclear power facilities. An environmental surveillance program is presented to achieve uniformity so that the data will be compatible and subject to singular interpretation relative to the estimated population radiation dose. The basic concepts presented may also apply to surveillance around other nuclear facilities such as gas-cooled and liquid-metal-cooled nuclear power facilities and nuclear fuel reprocessing plants. However, as additional nuclear facilities of these types are licensed and operated, additional guides may be needed. This Guide recommends procedures but does not establish the requirements for any particular organization for conducting environmental surveillance.

Radionuclides released with the effluents from nuclear power facilities become dispersed in the environment and contribute some radiation dose to the population. Environmental radiation surveillance programs conducted around nuclear power facilities should as a minimum provide data which may be used (1) for population dose calculations which can be compared with Federal and State standards, (2) for the evaluation of buildup of environmental radioactivity, and (3) for public information purposes.

Technical information for development of this Guide was obtained from radiological surveillance studies conducted by the Environmental Protection Agency (EPA) at an operating boiling water reactor (*1*) and an operating pressurized water reactor (*2*). These studies provide information on quantities and characteristics of radioactive material released to the environment and on critical pathways by which the public may potentially be exposed as a result of the releases.

CHAPTER 2

Environmental Surveillance Protocol

The offsite environmental surveillance program for a light-water-cooled nuclear power station should be established on the basis of an evaluation of radionuclide composition of the liquid and gaseous waste discharges from the facility and the environmental parameters that could affect their dispersion and dilution in the environment.

The recommended surveillance program consists of two phases: the preoperational and the operational. The preoperational phase provides data which can be used as a basis for evaluating increases in radioactivity in the vicinity of the plant after the plant becomes operational. The evaluation must also include a determination as to whether an increase is attributable to plant operations or to a general increase in environmental radioactivity. Therefore, the operational surveillance program must include control data from sample sites considered to be beyond the measurable influence of the nuclear facility as well as data from the areas expected to be most affected. The operational surveillance program will provide the data required for estimation of population dose. This dose may be compared with that calculated using a dose model and radionuclide discharge data for the specific nuclear facility. In all cases, the surveillance program must emphasize sampling and measurement of the environmental media which contribute most significantly to radiation exposure of the public. Chapter 4 provides guidance on population dose estimation.

Preoperational Environmental Surveillance

Preoperational radiation surveillance of the environment around nuclear power reactors should be carried out for 1 year prior to facility operations. This program consists of (1) identification of the probable critical exposure pathways, and (2) the critical population groups; (3) selection of the sample media and sample site locations; (4) the collection and analysis of environmental samples, and (5) the interpretation of the data.

The extent of preoperational surveillance depends upon the particular environment in which the reactor is located. If the effect of the initial reactor in a reactor complex is to be studied, the environmental surveillance and training will be more extensive than that required for startup of other reactors in the same reactor complex. A minimum preoperational surveillance program to be undertaken 1 year prior to facility operations is outlined as follows:

1. Make gamma radiation dose rate measurements (i.e., TLD, film badge, or pressurized ion chamber) at locations identified for direct radiation measurement in table 1. The locations may be chosen on the basis of meteorological data supplied with the Preliminary Safety Analysis Report for the facility.

2. Make *in situ* quantitative gamma spectrometric measurements at the stations in item 1. Analyze the spectra to apportion the total gamma dose rate among the various contributing radionuclides. Beck et al. (*3*) provide guidance and procedures for performing these measurements. Laboratory analysis of soil and other terrestrial materials contributing to ambient gamma dose levels may be substituted for the *in situ* measurements where practical.

3. Collect low volume air samples at one station for 6 months before startup and determine the gross beta activity. Perform gamma isotopic analyses[1] of a monthly composite of these samples.

4. Identify the critical population in the plant environs. Collect relevant demographic data for the area within 50 miles of the facility.

5. Collect samples of water, food, and biota along critical dose pathways. Perform gamma isotopic analyses. These samples should be collected and analyzed quarterly where appropriate to identify seasonal variations.

6. Long-lived alpha-emitting radionuclides such as radium-226, thorium-232, and plutonium-238/239, though not normally attributed to light-water-cooled power reactor operations, have been detected in environmental samples. Additional gross or specific alpha analyses during the preoperational phase may be required to fully document the population radiation exposure situation in the vicinity of the nuclear facility.

   Gross alpha and/or gross beta screening of environmental samples may be substituted for gamma spectroscopy during the preoperational phase.

[1] See footnote (a) to table 1 for definition.

Operational surveillance

The operational surveillance program should begin at the time the plant becomes operational. Specific media to be monitored during the initial phase of the operational program should have been identified during the preoperational surveillance program. Atomic Energy Commission (AEC) regulations (*4*) require that each nuclear power facility operator reports semiannually to the Commission the quantity of each of the principal radionuclides released to the environment in liquid and gaseous effluents. This information and other data on distribution of radionuclides in environmental media can be used to determine the population exposure pathways that should be monitored and to identify media in which there is potential for long-term buildup of radioactivity. Figures 1 and 2 show the most important population exposure pathways and these are listed below in order of general significance.

For atmospheric discharges

(1) Atmospheric discharge→ whole body external exposure.
(2) Atmospheric discharge → inhalation exposure.
(3) Atmospheric discharge → deposition on grass → cattle → milk → man.
(4) Atmospheric discharge → deposition on leafy vegetables → man.
(5) Atmospheric discharge → deposition on grass → cattle → beef → man.
(6) Atmospheric discharge → deposition on soil → plants → man.

For liquid discharges

(1) Aqueous discharge → waterway → drinking water supply → man.
(2) Aqueous discharge → waterway → seafood/fish → man.
(3) Aqueous discharge → waterway → aquatic plants → animals → man.
(4) Aqueous discharge → waterway → external exposure.
(5) Aqueous discharge → waterway → sediments → external exposure.

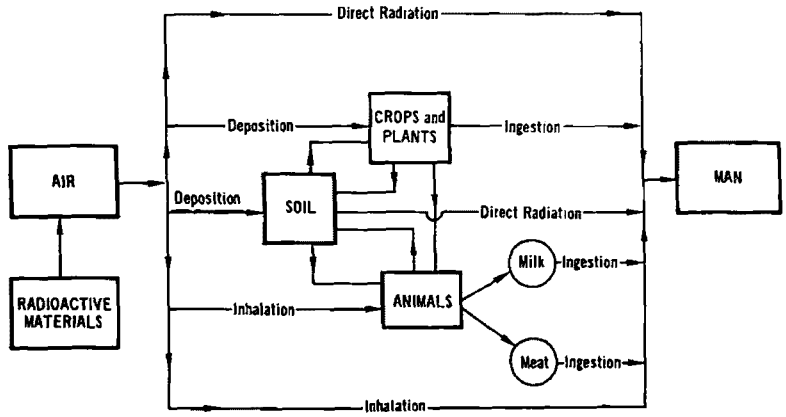


Figure 1. Pathways between radioactive materials released to the atmosphere and man (5)

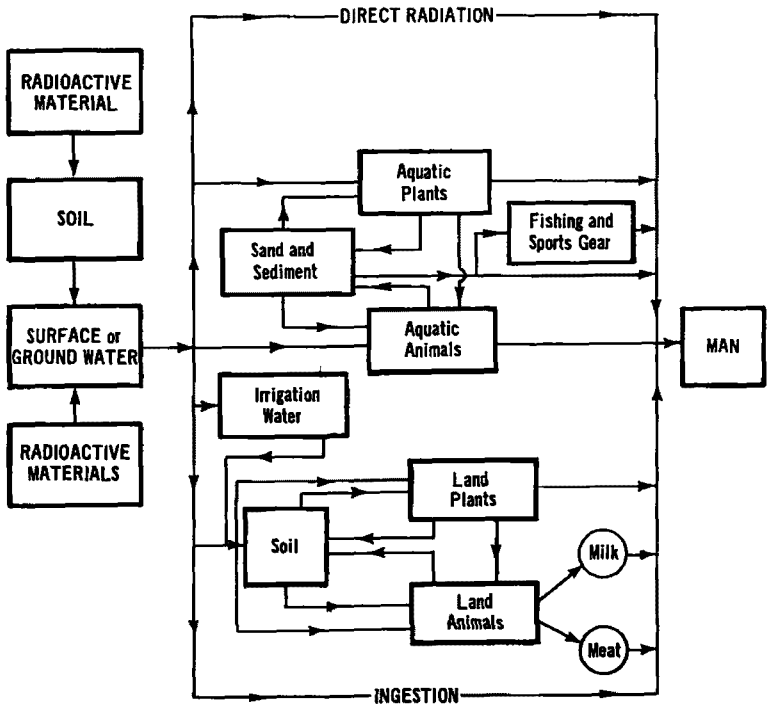


Figure 2. Pathways between radioactive materials released to ground and surface water (including oceans) and man (5)

Table 1. Offsite surveillance of operating light-water-cooled nuclear power facilities

Operation or sample type	Approximate number of samples and their locations	Collection frequency	Analysis type[a] and frequency
Air particulates	1 sample from the 3 locations of the highest offsite ground level concentrations 1 sample from 1-3 communities within a 10-mile radius of the facility 1 sample from a location greater than a 20-mile radius in the least prevalent annual wind direction[d]	Continuous collection—filter change as required	Gross long-lived β at filter change[b] Composite for gamma isotopic analysis and radiostrontium analysis[c] quarterly
Air iodine	Same sites as for air particulates	Continuous collection—canister changes as required	Analyze weekly unless absence of radioiodine can be demonstrated
Direct radiation	2 or more dosimeters placed at each of the locations of the air particulate samples which are located at the 3 highest offsite ground level concentrations 2 or more dosimeters placed at each of 3 other locations for which the highest annual offsite dose at ground level is predicted[e] 2 or more dosimeters placed at each of 1-3 communities within a 10-mile radius of the facility[f] 2 or more dosimeters placed at a location greater than a 20-mile radius in the least prevalent annual wind direction[d]	Quarterly	Gamma dose quarterly
Surface water[g]	1 upstream 1 downstream after dilution (e.g., 1 mile)	Monthly (Record status of discharge operations at time of sampling)	Gross β, gamma isotopic analysis[h] monthly. Composite for tritium and radiostrontium analysis[c] quarterly
Ground water	1 or 2 from sources most likely to be affected	Quarterly	Gross β, gamma isotopic analysis[h] and tritium quarterly
Drinking water	Any supplies obtained within 10 miles of the facility which could be affected by its discharges or the first supply within 100 miles if none exists within 10 miles	Continuous proportional samples[i]	Gross β, gamma isotopic analysis[h] monthly. Composite for tritium and radiostrontium analysis quarterly[c]
Sediment, benthic organisms and aquatic plants	1 directly downstream of outfall[j] 1 upstream of outfall[j] 1 at dam site downstream or in impoundments[j]	Semiannually	Gamma isotopic analysis semiannually
Milk	1 sample at nearest offsite dairy farm in the prevailing downwind direction 1 sample of milk from local dairy representative of milkshed for the area	Monthly	Gamma isotopic analysis and radiostrontium analysis monthly[c]
Fish and shellfish	1 of each of principal edible types from vicinity of outfall 1 of each of the sample types from area not influenced by the discharges	Semiannually	Gamma isotopic analysis semiannually on edible portions
Fruits and vegetables	1 each of principal food products grown near the point of maximum predicted annual ground concentration from stack releases and from any area which is irrigated by water in which liquid plant wastes have been discharged 1 each of the same foods grown at greater than 20 miles distance in the least prevalent wind direction	Annually (At harvest)	Gamma isotopic analysis annually on edible portions
Meat and poultry	Meat, poultry, and eggs from animals fed on crops grown within 10 miles of the facility at the prevailing downwind direction or where drinking water is supplied from a downstream source	Annually during or immediately following grazing season	Gamma isotopic analysis annually on edible portions
Quality control[k]	Samples as required for accurate sampling and analysis		Minimum frequency—annually

[a] Gamma isotopic analysis means identification of gamma emitters plus quantitative results for radionuclides that may be attributable to the facility.

[b] Particulate sample filters should be analyzed for gross beta after at least 24 hours to allow for radon and thoron daughter decay.

[c] Radiostrontium analysis is to be done only if gamma isotopic analysis indicates presence of cesium-137 associated with nuclear power facility discharges.

[d] The purpose of this sample is to obtain background information. If it is not practical to locate a site in accordance with the criterion, another site which provides valid background data should be used.

[e] These sites based on estimated dose levels, as opposed to ground level concentrations where the dose may be affected by sky shine, high plumes, or direct radiation from the facility being monitored.

[f] These locations will normally coincide with the air particulate samplers used in the monitored communities.

[g] For facilities not located on a stream, the upstream sample should be a sample taken at a distance beyond significant influence of the discharges. The downstream sample should be taken in an area beyond the outfall which would allow for mixing and dilution. Upstream samples taken in a tidal area must be taken far enough upstream to be beyond the plant influence when the effluent is actually flowing upstream during incoming tides.

[h] If gross beta exceed 30 pCi/liter.

[i] Drinking water samples should be taken continuously at the surface water intake to municipal water supplies. Alternatively, if a reservoir is used, drinking water samples should be taken from the reservoir monthly. If the holding time for the reservoir is less than 1 month, then the sampling frequency should equal this holdup time. Increases in concentration of activation and/or fission products at these sources necessitate the analysis of tap water for the purpose of dose calculations. Additional analyses of tap water may be necessary to satisfy public demand.

[j] See figure 6 for locations on a stream. For facilities located on large bodies of water, sampling sites should be located at the discharge point and in both directions along the shore line.

[k] The Analytical Quality Control Service of the Surveillance and Inspection Division (SID) provides low-level radiochemical standards and interlaboratory services to State and local health departments, Federal and international agencies, and nuclear power facilities and their contractors. The Service operates several types of cross-check programs for the analysis of radionuclide in environmental media, such as milk, food, water, air, and soil. The samples are submitted on a routine schedule designed to fit the needs of each laboratory. Technical experiments are undertaken to permit detailed analyses of the accuracy and precision obtained by participating laboratories. In addition, low-level radioactivity standards are provided to the agencies participating in the various programs. Primary and secondary standardization is also performed as needed on those radionuclides not used on a routine basis.

A recommended minimum level environmental surveillance program is presented in table 1. This table is a guide and should not be followed literally as though it were a regulation. There is no substitute for good professional judgment in the development of a surveillance program. The recommended program includes monitoring of four basic exposure pathways (air, water, food, and external radiation) and certain indicators of environmental trends. It is anticipated that only a portion of the listed food pathways will be critical or predominant pathways for population or individual radiation exposure at specific sites. Therefore, it will not be necessary to routinely monitor all pathways listed. However, air particulates, direct radiation, and surface water should be monitored even though they may not be critical or predominant pathways of exposure.

Environmental conditions around nuclear facilities will vary and it may be necessary to modify portions of table 1 according to the individual site characteristics. Because of ethnic or cultural differences, some individuals may select diets which others would not. There may also be economic or availability factors. For example, fishermen might consume much more fish or other seafoods than the normal population.

The control sample sites should be located so that they will be beyond measurable influence by the plant in question or by other nuclear facilities. State fallout networks are good sources of control data for some sample media if the sampling and analyses are done on the same basis; that is, with the same type of equipment, the same type of media and the same delay time.

Quality control should be exercised and confirmed for all sample analyses. The EPA Office of Radiation Programs' Analytical Quality Control Service is described in footnote (k) of table 1.

Periodically (e.g., biennially), *in situ* quantitative gamma spectrometric measurements should be performed to characterize any increases in environmental radiation levels. The spectra should be analyzed to apportion the total gamma dose rate among the various contributing radionuclides. The routine surveillance program should be evaluated at this time to determine if the program needs modification. This evaluation should be made on the basis of:

(1) Changes in quantity or characteristics of discharges as compared to predicted or actual circumstances on which the previous program was based,

(2) Analyses of samples of media that are not routinely monitored but which, on the basis of research or experience at other sites, have potential for population exposure or long-term buildup of radioactivity, and

(3) Experience with the existing program which may indicate that deletion of certain media or modification of the frequency, type of analysis, or sampling techniques would not compromise the program.

CHAPTER 3

Sampling and Analysis

The selection of sampling equipment and the techniques used for collecting environmental samples are important considerations in environmental radiation surveillance programs around nuclear power facilities. The choice of sampling equipment, method of sample preparation, and counting instruments are dependent on the radionuclide composition and quantity of radioactive material released to the environment. Because of low radionuclide concentrations in environmental media, special methods of analysis and sampling techniques have been developed. Specialized techniques for measuring environmental radioactivity resulting from liquid and gaseous effluents from light-water-cooled reactors have been reported (*6-14*). Tables 2 and 3 provide references to analytical techniques which are currently in use by monitoring organizations and which are suitable for use with procedures discussed in this Guide. If the sampling procedures or analytical techniques contained in this Guide are not used, the analytical laboratory should assure accuracy and precision equivalent to those included in tables 2 and 3.

All samples should be accompanied by information which identifies the sample site, date of collection, type of sample and the collector. It may be desirable to assign a sample number in order to follow the sample through a series of analyses. Perishable samples which must be saved for later analysis should be frozen or chemically preserved. Sealable plastic bags or polyethylene bottles are generally recommended for collection and storage of samples.

Air Particulate Sampling Equipment

Particulate samples are normally collected on a filter medium with an air pump and a flow-measuring device. Samples can be used individually for beta radioactivity measurements and composited for radionuclide analysis, particle size studies, autoradiography, and the like. Since gamma spectrometric analysis may also be required in addition to gross beta determination, a sample size of 300 m^3 or more is recommended. A continuous flow rate of 1 cubic foot per minute for 1 week provides 285 m^3 total volume.

The air sampling system should have a flow-rate or flow integrating meter and should be mounted in an all-weather shelter with the sampler discharge located so as to prevent the recirculation of air. A charcoal cartridge should follow the particulate filter for collection of iodine. If flow-rate monitoring is used, power outages or other factors which affect the data should be automatically recorded.

Air Sampling Locations

Low volume samplers should be placed at three sites of maximum predicted ground level

Table 2. Detection capabilities associated with analytical methods of environmental radioactivity surveillance

Media and isotope	Analytical method from table 3	Sample size	Minimum detectable levels[a]	Annual dose associated with MDL (mrem/yr)[b]	Assumption for dose model: Critical organ	Assumption for dose model: Annual intake[c]
Air particulates:						
Gross beta	E	300 m^3	3×10^{-3} pCi/m^3		Bone	7,300 m^3
^{89}Sr	F	1,200 m^3	5×10^{-3} pCi/m^3	0.025	Bone	7,300 m^3
^{90}Sr	F	1,200 m^3	1×10^{-3} pCi/m^3	.05	Bone	7,300 m^3
^{134}Cs	A	1,200 m^3	1×10^{-2} pCi/m^3	.005	Total body	7,300 m^3
^{137}Cs	A	1,200 m^3	1×10^{-2} pCi/m^3	.0025	Total body	7,300 m^3
^{140}Ba-La	A	1,200 m^3	1×10^{-2} pCi/m^3	.0038	GI (LLI)	7,300 m^3
Air gases:						
^{131}I	A	300 m^3	4×10^{-2} pCi/m^3	1.0	Thyroid	[d]1,710 m^3
Short-lived gases	B	Not applicable	[e]20 mrem/yr	20	Total body	Not applicable
^{85}Kr	C	1 m^3	1 pCi/m^3	.002	Skin	Not applicable
^{3}H (HTO)	D	10-15 ml of condensate	5×10^{-3} pCi/m^3	.000013	Body Tissue[g]	7,300 m^3
Water:						
^{58}, ^{60}Co	A	100 ml	20 pCi/liter	[h].32	GI (LLI)	440 liters
^{58}Co	B	3.5 liters	10 pCi/liter	.082	GI (LLI)	440 liters
^{60}Co	B	3.5 liters	10 pCi/liter	.16	GI (LLI)	440 liters
^{140}Ba-La	B	3.5 liters	10 pCi/liter	.41	GI (LLI)	440 liters
	H	1 liter	1.0 pCi/liter	.041		
	I	1 liter	1.0 pCi/liter	.041		
^{3}H	J	4-5 ml	200 pCi/liter	.018	Body tissue	440 liters
	K	10-15 ml	200 pCi/liter	.018		
	L	10-50 ml	400 pCi/liter	.036		
^{14}C	M	200 ml	30 pCi/liter	.031	Fat	440 liters
	S	500 ml	.6 pCi/liter	.0006		
^{89}Sr	N	1 liter	5 pCi/liter	1.4	Bone	440 liters
	O	1 liter	5 pCi/liter	1.4		
	P	1 liter	5 pCi/liter	1.4		
	R	1 liter	5 pCi/liter	1.4		
^{90}Sr	N	1 liter	1.0 pCi/liter	2.7	Bone	440 liters
	O	1 liter	1.0 pCi/liter	2.7		
	P	1 liter	1.0 pCi/liter	2.7		
	Q	1 liter	1.0 pCi/liter	2.7		
^{134}, ^{137}Cs	B	1 liter	1.0 pCi/liter	.03	Total body	440 liters
^{134}Cs	C	3.5 liters	10 pCi/liter	.30	Total body	440 liters
^{137}Cs	C	3.5 liters	10 pCi/liter	.14	Total body	440 liters
^{65}Zn	B	3.5 liters	20 pCi/liter	.054	Total body	440 liters
^{54}Mn	B	3.5 liters	10 pCi/liter	.082	GI (LLI)	440 liters
	D	400 ml	40 pCi/liter	.32		
^{55}Fe	E	100 ml	20 pCi/liter	.02	Spleen	440 liters
^{59}Fe	B	3.5 liters	20 pCi/liter	.27	GI (LLI)	440 liters
	E	100 ml	100 pCi/liter	1.4		
^{131}I	B	3.5 liters	10 pCi/liter	27	Thyroid	440 liters
	F	100 ml	10 pCi/liter	27		
	T	10 liters	.04 pCi/liter	.1		
^{95}Zr-Nb	B	3.5 liters	5 pCi/liter	.071	GI (LLI)	440 liters
^{95}Zr	G	200 ml	15 pCi/liter	.21		
^{95}Nb	G	200 ml	25 pCi/liter	.21	GI (LLI)	440 liters
Milk:						
^{89}Sr	B	1 liter	5 pCi/liter	1.2	Bone	365 liters
	C	1 liter				
	D	1 liter				
^{90}Sr	A	1 liter	1 pCi/liter	2.3	Bone	365 liters
	B	1 liter				
	C	1 liter				
	D	1 liter				
^{131}I	E	3.5 liters	10 pCi/liter	50	Thyroid	365 liters
^{134}Cs	E	3.5 liters	10 pCi/liter	.25	Total body	365 liters
^{137}Cs	E	3.5 liters	10 pCi/liter	.11	Total body	365 liters

See footnotes at end of table.

Table 2. Detection capabilities associated with analytical methods of environmental radioactivity surveillance continued

Media and isotope	Analytical method from table 3	Sample size	Minimum detectable levels[a]	Annual dose associated with MDL (mrem/yr)[b]	Assumption for dose model: Critical organ	Assumption for dose model: Annual intake[c]
Shellfish (fish):						
^{58}Co	A	200 grams	80 pCi/kg	.027	GI (LLI)	18.25 kg
^{60}Co	A	200 grams	80 pCi/kg	.054	GI (LLI)	18.25 kg
^{134}Cs	A	200 grams	80 pCi/kg	.1	Total body	18.25 kg
^{137}Cs	A	200 grams	80 pCi/kg	.046	Total body	18.25 kg
^{65}Zn	A	200 grams	160 pCi/kg	.018	Total body	18.25 kg
^{54}Mn	A	200 grams	80 pCi/kg	.027	GI (LLI)	18.25 kg
^{59}Fe	A	200 grams	160 pCi/kg	.091	GI (LLI)	18.25 kg
^{55}Fe	B[d]	100 grams	20 pCi/kg	.00028	Spleen	18.25 kg
^{89}Sr	C	200 grams	25 pCi/kg	.28	Bone	18.25 kg
	D	200 grams	25 pCi/kg	.28		
^{90}Sr	C	200 grams	5.0 pCi/kg	.55	Bone	18.25 kg
	D	200 grams	5.0 pCi/kg	.55		
	E	200 grams	5.0 pCi/kg	.55		

[a] The minimum detectable levels (MDL) are practical detection levels, rather than theoretical detection levels. These levels are characteristic of the analytical procedure and the counting instrumentation in use. The MDL's listed assume the following instrumentation: (1) low background beta counter, (2) standard gamma scan—400 to 512 multichannel analyzer—4-by 4-inch NaI(Tl) detector, and (3) tritium—liquid scintillation counter. The detection limit for a specific radionuclide by gamma spectrometry is dependent upon the quantities of other radionuclides present in the sample. The detection limits tested are those practically obtained with the concentrations and mixtures of radionuclides normally encountered with environmental samples. If only a single radionuclide is present in a sample to be analyzed by gamma spectrometry, then the detection limits listed could probably be reduced by a factor of 2. The detection limits for specific nuclides would be considerably greater than those listed when complicated mixtures are encountered and in particular when certain constituents are present in relatively high concentrations.

[b] These values were obtained by a simple ratio relating Radiation Protection Guides of the Federal Radiation Council (*34*) to the dose associated with these Guides. Actual dose calculations resulting from specific environmental levels should take into consideration additional factors relating to pathways, intake and other environmental factors as appropriate.

[c] Intake values assume standard man quantities or other referenced values as follows:

1. 1 liter of milk per day for a 1-year-old child (*17*).
2. 1.2 liters of water per day, adult (*18*).
3. 20 cubic meters of air breathed per day for an adult (*18*).
4. 4.7 cubic meters of air breathed per day for a 1-year-old child (*17*).
5. 1.87 kilograms of food consumed per day for total diet of a teenager (*19*).
6. 50 grams per day of shellfish (*20*).

[d] The annual intake of air is for a child (age 1 year). In the case of ^{131}I, the child thyroid is the limiting factor.

[e] CaF_2:Mn dosimeter encapsulated in ^{40}K-free glass or equivalent.

[f] Assuming temperature of 75° Farenheit and 90 percent relative humidity.

[g] The critical organ for ^{3}H gas may be the skin, depending upon the state of the ^{3}H (gaseous or oxide). The body tissue is used as the most conservative case.

[h] Assumed worst case mixture of 100 percent of ^{60}Co.

[i] Procedure B under shellfish is for aqueous solutions so that preliminary sample preparation is necessary prior to entering this procedure.

concentration of stack releases, averaged over a period of a year. Additionally, air sampling stations should be located at one to three communities within a 10-mile radius of the facility and at a distant control site 20 or more miles away in the prevailing upwind direction.

Considerable judgment must be exercised in selection of air sampling sites. The following is a technical approach to air sample site selection based on average meteorological conditions. These conditions are subject to variability, and site selections should be adjusted as necessary, considering accessibility of the sample site, availability of power to run the equipment, equipment security, and environmental conditions such as unusually dusty air.

The locations of the maximum ground level concentrations may be identified by using the graph in figure 3 in combination with prevailing wind direction data. The distance of the sampling site from the point of discharge will be determined from figure 3 by using the appropriate stack height and the predominant stability conditions. The direction may be determined from wind rose information using the prevailing wind directions. Atmospheric stability data and wind rose data are generally available in the Preliminary Safety Analysis Report prepared by the facility operator in application to the AEC for a permit or license to construct or operate the facility. The wind rose data may be plotted as a function of at-

Table 3. Analytical methods for routine environmental radioactivity surveillance

Media	Code	Analytical method	References
Air	A	Gamma Spectrometry for Iodine-131 of Air Filters or Cartridge Samples (6.2.2.)	(8)
	B	Dosimeter-External Exposure	(13)
	C	Cryogenic Separation and Liquid Scintillation Counting	(21)
	D	Determination of Tritium in Water	(9, 14)
	E	Gross Beta Counting of Air Filters (6.2.1)	(8)
	F	Oxalate Precipitation (6.2.6)	(8)
Water	A	Cobalt and Nickel	(10)
	B	Gamma Analysis in Water (5.2.6)	(8)
	C	Cesium—Phosphomolybdate—Chloroplatinate Method	(10)
	D	Radioactive Manganese (ASTM D2039-69)	(10)
	E	Radioactive Iron (ASTM D2461-69)	(10)
	F	Radioactive Iodine Distillation (ASTM D2334-68)	(10)
	G	Zirconium-Niobium-95	(10)
	H	Basic Carbonate Method (5.2.3)	(8)
	I	Radioactive Barium (ASTM D2038-68)	(10)
	J	Radioactive Tritium (ASTM D2476-69)	(10)
	K	Determination of Tritium in Water	(9, 14)
	L	Distillation Method—Tritium (5.2.5)	(8)
	M	Carbon-14—Distillation to $CaCO_3$	(10)
	N	Basic Carbonate Method for Saline Water (5.2.2)	(8)
	O	Radiostrontium in Saline Water (5.2.2)	(8)
	P	Oxalate Precipitation Method (5.2.2)	(8)
	Q	TBP Extraction (Strontium-90) (5.2.2)	(8)
	R	Difference Method (Strontium-89) (5.2.2)	(8)
	S	Carbonate Carbon-14 by Liquid Scintillation Counting	(22)
	T	Iodine-131 by Ion Exchange and Precipitation	(22)
Milk	A	Reference Method—TBP Extraction (3.2.1)	(8)
	B	TCA Precipitation Method—Nitric Acid Separation (3.2.2)	(8, 9)
	C	Ion-Exchange Procedure—TBP Extraction (3.2.3)	(8, 9)
	D	Batch Ion-Exchange Procedure—TBP Extraction (3.2.3)	(8)
	E	Gamma Spectrometry on Milk (3.2.4)	(8)
Shellfish	A	Gamma Spectrometry of Soft Tissue (7.2.6)	(8)
	B	Radioactive Iron (ASTM D2461-69)	(10)
	C	TTA Extraction Method (4.2.2)	(8)
	D	TBP Extraction Method (4.2.3)	(8)
	E	HDEHP Extraction Method (4.2.1)	(8)

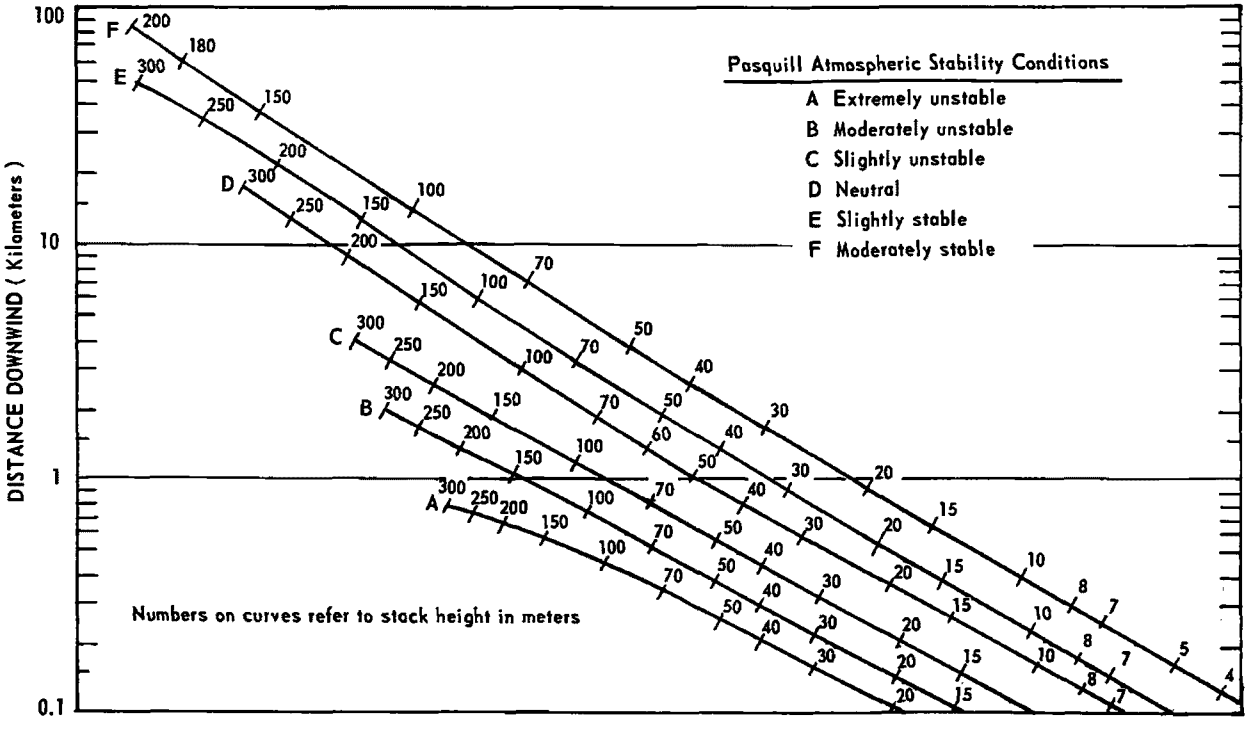


Figure 3. Estimated distance of maximum ground level concentration as a function of Pasquill atmospheric stability conditions and stack height in meters (*15*)

mospheric stability condition; i.e., there would be a wind rose for each condition. In this instance, the sample sites would be located along the radii of each prevailing wind direction at a distance from the stack as indicated in figure 3, for the respective stability condition. However, wind rose data are usually provided on an annual average basis. These plots may be used by selecting the three principal average wind directions and locating the sample sites at a distance from the release point based on the height of release and predominant annual stability condition as indicated in figure 3. As an alternative, the prevailing average wind direction could be determined and the three sample sites would then be located along that radius at distances based on the release height and the three prevailing stability conditions. This procedure or a combination with the first alternative using annual average data might be the best choice particularly in instances where one of the prevailing wind directions is over water or other inaccessible area.

Figure 4 provides an example of sampling sites located by using annual average wind rose data which have been plotted as a function of atmospheric stability conditions. (Remember that the petals of a wind rose generally point in the direction from which the wind blows and therefore the sampling site would be in the opposite direction.) In this example, it is assumed that stability condition B exists 40 percent of the time, condition C 30 percent, and condition D 20 percent. It is further assumed that the major portion of gaseous discharges will be from a 100-meter stack.

Figure 5 shows two examples of sampling site locations based on the annual average wind rose for the same site and conditions as in figure 4. Example 1 is based on the three prevailing wind directions and the predominant atmospheric stability condition, whereas example 2 is based on the single prevailing wind direction and the three predominant stability conditions. Other similar procedures may be used depending on types of meteorological data available.

Direct Radiation

A network of integrating or continuously recording dosimeters (TLD, film, or ion chambers) should be placed at sites around the nuclear facility as indicated in table 1. The recommended height for placement of the dosimeters is at 3 feet above the ground. If other heights are used, the relationship to the 3 foot dose should be established for the site.

Where integrating dosimeters are used, two or more dosimeters should be located at each site. Additionally, it is advisable to use a set of dosimeters at each site for long-term exposure (e.g., 6 months or 1 year) in addition to the set changed quarterly. Integrating dosimeters should be read as quickly as possible following collection. For TLD, the date annealed should be recorded and the time lapse from date annealed to date read should be used to compute the dose. Integrating dosimeters should not be sent to a distant location for processing unless evidence can be provided to show that adequate precautions are taken to avoid significant additional exposure. For example, they may be exposed to other sources of radiation such as shipments of radioactive materials or high altitude cosmic radiation in aircraft.

Water Sampling

The size of water samples will be determined by the analytical procedure to be used and the desired minimum detectable concentration of the radionuclide of concern. A 3.5-liter (approximately 1 gallon) sample is usually required for gamma isotopic analysis. This quantity should be doubled where split sampling is planned. Ion exchange procedures using resin columns are frequently used for larger volume samples. These procedures may be advantageous for continuing sampling processes except for those samples requiring tritium analysis.

Surface water grab samples should be collected from at least two sites. One site should be located upstream from the facility discharge outfall. This site will provide control data for comparison with data from a second site downstream from the discharge. If the nuclear facility is located on a body of water other than a stream, the control sample should be taken far enough from the point of discharge so that the facility effluent has little or no influence on the sample content. When a reactor is located on

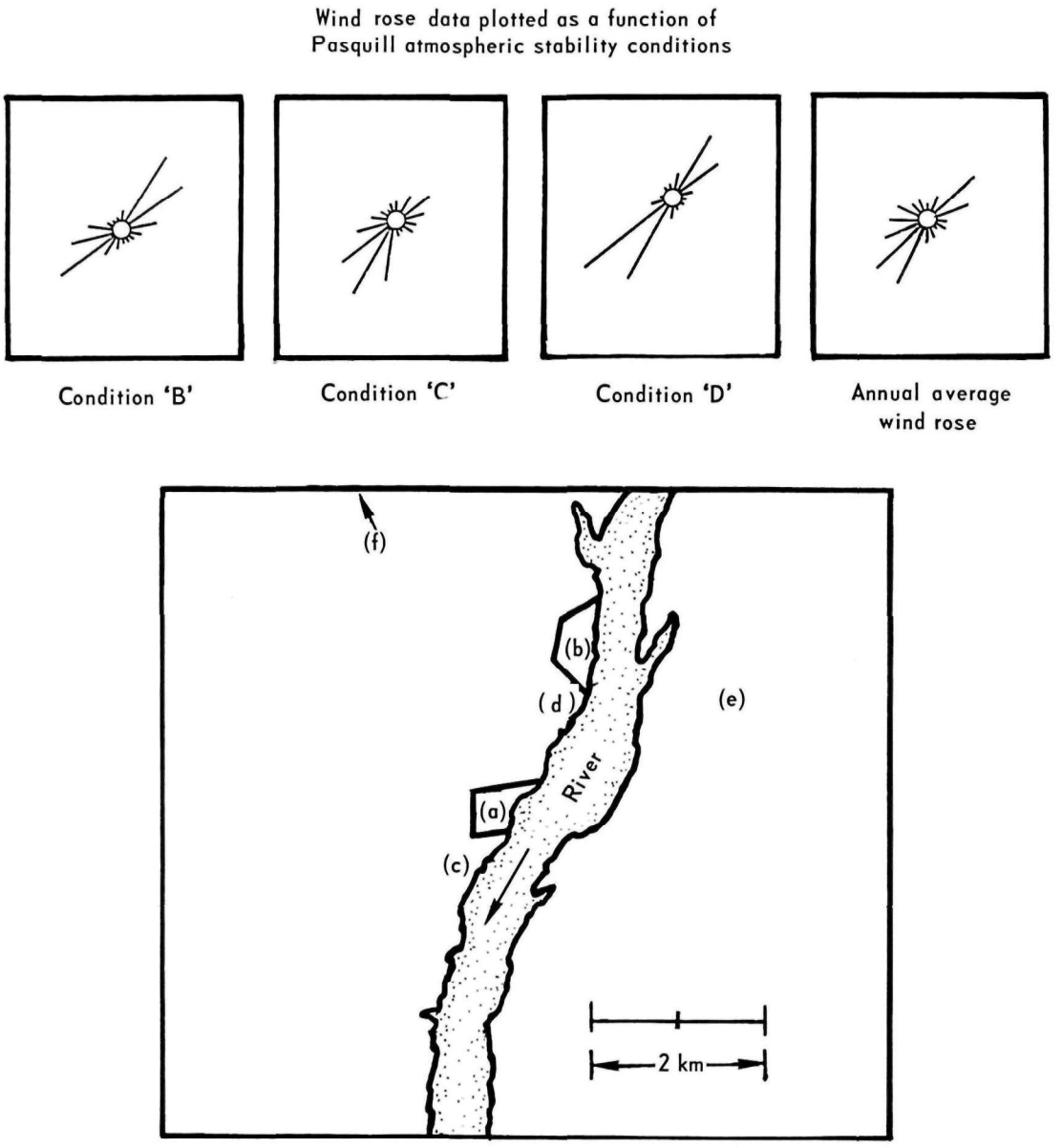
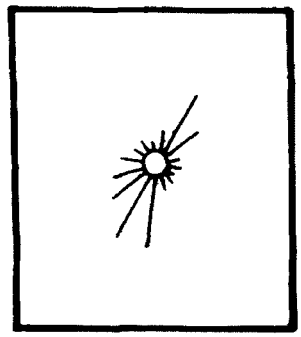


Figure 4. Air particulate sample site around a nuclear power facility based on Pasquill atmospheric stability conditions

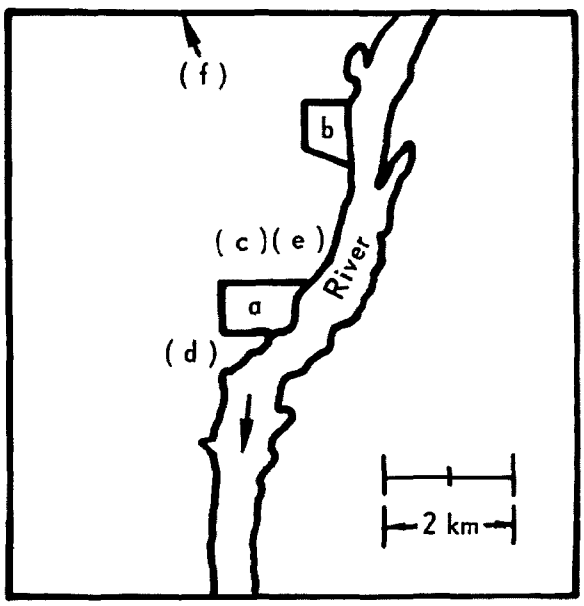
(a) Facility site
(b) Community sample site
(c) Site at 0.7 km based on condition 'B'
(d) Site at 1.2 km based on condition 'C'
(e) Site at 3 km based on condition 'D'
(f) Control site at >20 km based on annual average wind rose

an estuary where the direction of flow is affected by tidal action, the control sample should be taken far enough upstream to avoid contamination by the tidal action. The second site should be located downstream from the discharge outfall. The discharge-to-downstream-site distance should, as a rule of thumb, be at least 10 times the river width to allow for mixing. For those facilities located on a lake or ocean, this site should be located near the discharge outfall but beyond the turbulent area caused by the discharge.



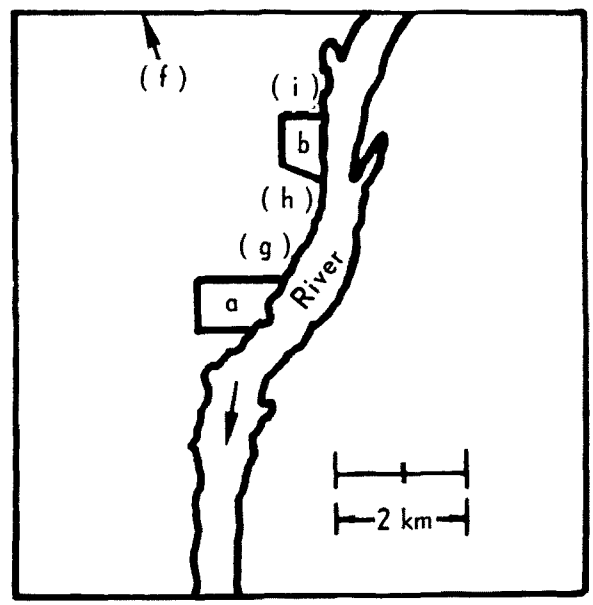
Annual average
wind rose

Example 1



Using 3 prevailing wind directions and stability condition 'B' from figure 3

Example 2



Using the prevailing wind direction and stability conditions 'B,' 'C,' & 'D' from figure 3

Figure 5. Air particulate sample sites around a nuclear power facility based on annual average wind rose data

(a) Nuclear power facility site
(b) Community sample site
(c) Sample site at 0.7 km north based on stability condition 'B'
(d) Sample site at 0.7 km southwest based on stability condition 'B'
(e) Sample site at 0.7 km northeast based on stability condition 'B'
(f) Control site at >20 miles
(g) Sample site at 0.7 km north based on stability condition 'B'
(h) Sample site at 1.2 km north based on stability condition 'C'
(i) Sample site at 3 km north based on stability condition 'D'

The waste management procedures for liquid wastes result in periodic discharges. Thus, grab samples collected downstream from a nuclear facility are of questionable value. Ideally, a continuous proportional sampling device would be used. However, in the absence of a direct population exposure pathway from surface water, continuous sampling is generally not justifiable. As an alternative, one should collect grab samples and include a record of the discharge rate from the facility at the time the sample was taken. If the sampling site is more than a few minutes flow-time downstream, the record should show the rate of discharge at the time the water being sampled passed the point of discharge. This record should accompany the sample.

There is little possibility that *ground water* will accumulate radioactivity from nuclear power facility discharges. This is because these facilities are located adjacent to major streams or other large bodies of water and the natural underground water flow is toward these bodies of water. Further, the soil acts as a filter and ion exchanger and thus removes minerals present in underground seepage. Tritium is the principal radionuclide with substantial potential for seeping through the soil into ground water. Routine monitoring of offsite ground water will be unnecessary in most instances; however, in those instances where it is recommended, tritium should be given particular attention. However, there may be instances of surface water carrying contamination directly into ground water and additional radionuclides should be analyzed as indicated in table 1.

Drinking water supplied from a source which receives effluent from a nuclear power facility should be sampled on a continuous basis at the point of intake and/or at the tap for all public supplies within 10 miles which could be affected by facility discharges. In instances where there are no drinking water supplies within 10 miles, the first water supply within 100 miles should be monitored.

Sediment, Benthic Organisms and Aquatic Plants

Sediment samples are taken to indicate the buildup rate of radioactivity due to sedimentation. Figure 6 illustrates some suggested sampling locations in a stream from which routine sampling sites may be selected. Additional locations should be sampled occasionally to determine if routine sample sites should be relocated. The downstream sample should be taken in that part of the stream where the flow rate is greatest. Samples may also be taken in an area which favors sedimentation, such as the inner bank of a bend. For reactors located on a river a short distance upstream from the fresh-salt water interface at the river mouth, the downstream sediment sample should be taken within the interface. Precipitation and flocculation of the suspended silt occurs in this area, thereby increasing the concentration of radionuclide levels in the sediment. If the nuclear facility is located on a lake or ocean, a sediment sample should be taken near the outfall but beyond the turbulent area created by the outfall. The sediment sample should contain at least 1 kilogram and should consist of only the top layer or most recent sediment.

Aquatic plants and animals such as algae, seaweed, and benthic organisms should be sampled as part of the periodic surveillance program evaluation. If buildup in excess of 10 times the levels in the water is found in any of these media, that plant or animal should be added to the routine program as indicated in table 1. Sampling locations should be similar to those described for sediment.

Food Samples

Milk should be collected from dairy cows fed on fodder and pasturage grown within a 10-mile radius of the plant. If possible, one sample should be collected from cattle fed on vegetation grown in the downwind area of maximum predicted concentration. An additional sample should be collected from a local dairy representative of a milkshed for the area. Excessive dilution of samples with milk from unaffected areas should be avoided. At least a 1-gallon sample should be collected in polyethylene bottles and preserved with about 12 ml of 37 percent formaldehyde solution for later analysis. Alternatively, an ion exchange column may be used to separate radionuclides from the milk (*9*).

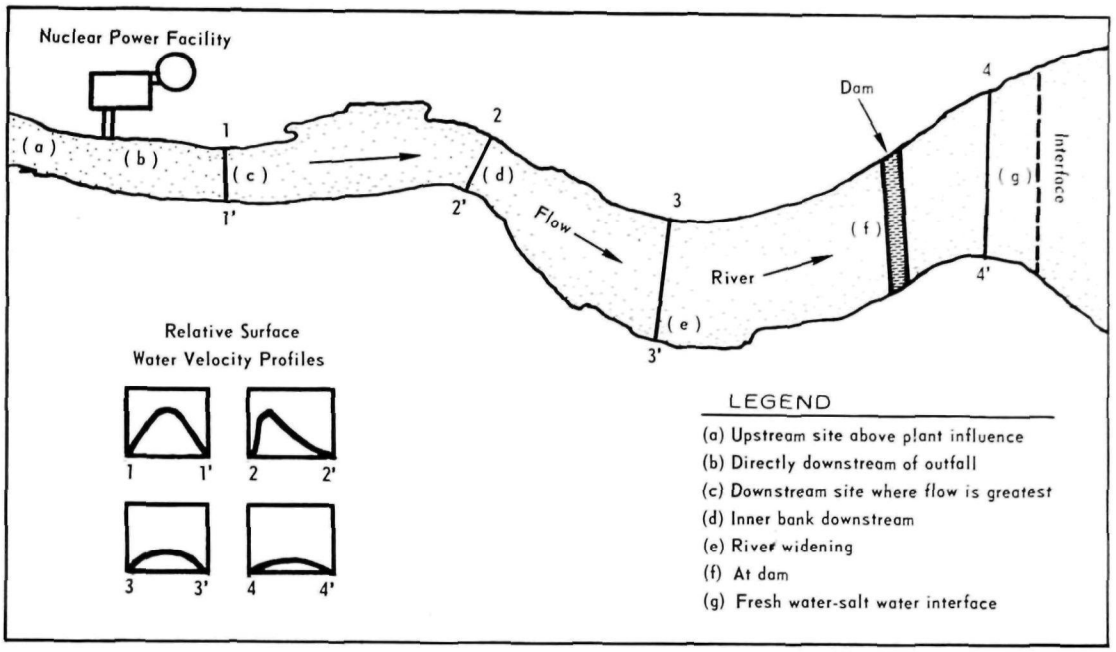


Figure 6. Suggested sediment sampling locations

Fish and shellfish samples should include each of the principal edible types in the facility environs. One sample should be taken from the vicinity of the outfall with an additional sample from the same body of water at a site not influenced by the discharge. The samples may be purchased from fishermen if the origin can be determined. Each sample should include 3.5 kilograms of edible flesh. (Care must be taken to separate fish flesh from bone.) However, if this quantity is not available, a 220-gram sample is recommended.

Fruit and vegetable samples should be collected near the point of maximum predicted annual ground concentration from stack releases and from areas which may be contaminated by water into which liquid plant wastes have been discharged. The primary sample should consist of at least 3.5 kilograms of the edible portion. Exposed surfaces of vegetation or fruit samples can provide indications of deposition and should not be washed.

Samples of *meat, poultry,* and *eggs* produced in the area should be collected. Meat samples may be collected at a slaughterhouse if the origin of the animals can be documented. The samples should represent animals fed on crops grown within 10 miles of the plant in the prevailing downwind direction. Samples from animals which drink from a source downstream of the discharge should also be included where available. To assure good geometry during gamma isotopic analysis, the sample collection should weigh at least 3.5 kilograms of the edible portion.

Analytical Quality Control Methods

Environmental samples contain such small quantities of radionuclides that highly refined detection capabilities must be developed and maintained. With samples being analyzed in many different laboratories, it is necessary that similar detection capabilities be available to assure comparability. A laboratory should develop and maintain uniform minimum detectable level capabilities and should routinely participate in an interlaboratory quality control program. A minimum quality control frequency should be 10 percent of all nuclide analyses including inhouse blanks, standards and splits.

Analytical quality control methods generally include cross checking or splitting samples with a laboratory such as an Environmental Protection Agency laboratory. A cross check involves the analyses of samples provided by a control laboratory and comparison of results with those of the control laboratory as well as with other laboratories which received portions of the same sample. Splitting a sample involves obtaining two identical samples from a single collected volume, with one sample being analyzed by the monitoring laboratory and the other by the control laboratory and subsequent comparison of results. When splitting samples for interlaboratory comparison, it is vital that both samples are representative of the media in question. Splitting procedures are listed below by media.

Air particulate filter paper should contain a symmetric distribution of deposition and may be cut exactly in half. Prior to cutting, the filter should be sprayed lightly with a plastic coating to prevent loss of the sample to the container.

To obtain a split of a *direct radiation measurement,* the sampling procedure must utilize multiple dosimeters. The exposures should be made side by side for exactly the same length of time and the dosimeters must be treated as similarly as possible, e.g., similar annealing or charging of dosimeters and similar exposure during storage or transit. Splitting the sample with a control laboratory may be impractical for short duration (1 quarter) exposures due to variable exposure in transit.

When *milk samples* are being taken at local farms, the collection should take place after milk has mixed thoroughly in the bulk storage tank or the individual samples should be mixed in the laboratory and then split into two separate containers.

Solid organic samples, such as fish, meat, and vegetables should be collected in a quantity equal to twice the normal sample. The sample should then be mixed thoroughly (blended where practical) and divided into separate containers.

Radioactive material in *water samples* may deposit on sample container walls and therefore it is desirable to obtain duplicate samples simultaneously in similar containers rather than split one large sample.

Sediment samples should be taken in duplicate. The total sample should be thoroughly mixed, halved, and bagged for shipment. The samples should be as uniform as possible taking care to avoid having larger particles concentrated in one sample.

Reporting Procedures

Reporting of data generated by the programs suggested in this Guide should be done following a clear and uniform format suitable for automatic data processing.

The reported information should generally include the following information:

1. Geographic location of sample site.
2. Sample type (media).
3. Sample number (optional).
4. Identification of organization or person collecting the sample.
5. Identification of organization analyzing the sample.
6. Time and date sample was taken (include duration of sample period for integrated samples).
7. Sample preparation as appropriate (e.g., concentration or wet vs. dry).
8. Type of analysis performed.
9. Value and units for each analysis and associated 2-sigma error.
10. Parameters needed to calculate decay of sample prior to analysis where short-lived radionuclides are involved.
11. Any known events that may have affected the analytical results.

Much of the above information, such as sample site location and organization identification, can be coded to reduce the record volume.

The reports should be distributed to State and Federal agencies on a set frequency, e.g., semiannually. Specifically, the Environmental Protection Agency's Office of Radiation Programs should receive the data periodically for inclusion into the National Environmental Radiation Monitoring Program. The Environmental Protection Agency recommends a format in the "National Environmental Radiation Data System" (*16*).

CHAPTER 4

Dose Estimations

Estimations of population dose from environmental radiation involves determination of the concentration of each radionuclide in ingestion and inhalation pathways and the use of mathematical models to convert these concentrations to whole body or organ dose. The whole body dose from this calculation is then added to the measured or calculated whole body dose from external exposure. The direct measurement of external dose or concentrations of radionuclides in environmental media attributable to the discharges of radioactive material from normal operations of nuclear power facilities will be difficult even with the most sensitive systems of radiation detection. The increment of dose to individuals at the facility boundary in instances where the facility maintains discharges within the AEC Design Guides (*23*) will be about one or two orders of magnitude less than the natural background dose. Variations in natural background radiation levels in many cases mask the increment of dose attributable to discharges from the nuclear facility. Therefore, it is generally more appropriate to estimate population dose based on known quantities and types of radionuclides discharged, considering the critical environmental pathways and the associated reconcentration factors. These estimates should be compared wherever possible to dose calculations based on environmental measurements. This comparison may not always be possible because in some instances calculations based on environmental measurements will determine only that the population dose resulting from nuclear facility discharges is below some level representing the minimum sensitivity of analysis. The data from exposure pathways, where environmental levels attributable to nuclear facility discharges are measurable, will provide a basis for the degree of confidence to be placed on the calculated concentrations based on discharges.

The models used to calculate concentrations of radionuclides in the environment should be tailored to represent the environmental and demographic characteristics of the area surrounding the site. The environmental characteristics include those relating to the meteorology, hydrology, and population exposure pathways. These pathways include external radiation exposure as well as internal exposure from inhalation and from ingestion of water and food. The food pathways may be unique to the environment in the area of the facility.

The collection of demographic characteristics of the area should include population locations and eating, recreational, and mobility habits. Further, the hypothetical maximum exposed individual should be identified. This would be an individual with the greatest potential for receiving a radiation dose from the facility

discharges. For example, this might be a person who lives at the location of the maximum average ground level concentration of the gaseous plume; he would eat food from the area having the greatest potential for radioactivity from plant discharges; his drinking water might be a cistern located at his residence or some other source of water identified as a critical pathway.

The demographic data should also identify the critical population group which is the group with the greatest potential for receiving radiation dose resulting from the operation of the facility. For example, the group may be fishermen who routinely utilize the marine life as a source of food, or the residents of a town whose drinking water would be influenced by the facility discharges. Some of the food may be grown locally, and the group may receive some external exposure from gaseous emissions. The demographic data should characterize the population density within a 50-mile radius of the site and should summarize the exposure pathways.

Mathematical models for calculation of concentrations in the environment based on discharges and for calculation of population dose based on environmental concentrations of radionuclides are available in various publications and no attempt is made to present them in this Guide. Rather, a list of sources of the information is provided with a brief discussion of each source.

Slade (*24*), chapters 7 and 8, is an excellent source of models and guidance for calculating environmental concentrations based on atmospheric discharges. He also provides models for converting the concentrations to population dose. These models may require modification to suit local conditions. For example, some coastal winds reverse direction twice per day, providing potential for buildup of concentrations.

General models for dispersion of liquid discharges may not be as readily available as those for gaseous discharges and selection of the proper model may require more consideration. Liquid discharges may be to a stream, an impounded stream, a fresh or salt water lake, an estuary, or to an ocean. Calculation of dose from liquid effluents involves the use of models that will provide concentrations as a function of discharge rate. Concentration estimates for streams can be made based on discharge rate, radioactive half-life and dilution factors. Similar estimates can be made for impounded streams and estuaries, with the addition of concentration factors due to recirculation. These factors are normally provided in the Safety Analysis Report prepared for a nuclear power facility. The use of these factors as the basis for calculating environmental concentrations resulting from liquid discharges generally results in a conservative estimate due to radionuclide depletion from precipitation, uptake by biological media, and many other processes. Okubo (*25*) provides a review of theoretical models for calculating dilution due to turbulent diffusion in the ocean. Baumgartner (*26*) provides a computer program for calculating dilution of pipeline discharges into lakes, reservoirs, estuaries, or the ocean. Crim (*27*) reviews the basic equations involved in modeling hydraulic and water systems and presents a general method of model construction. He also provides numerous logic diagrams for modeling specific flow situations.

Calculated concentrations in air and water provide a satisfactory base for calculating population dose from direct exposure, inhalation, and drinking water. However, the calculation of dose from ingestion of food requires the application of reconcentration factors of radionuclides by biological processes to determine the concentration of specific radionuclides in each food.

Models for calculating concentrations of radioiodine in milk resulting from reconcentration through the pasture-cow-milk pathway are provided in Peterson (*28*) and Burnett (*29*). Concentration factors in marine and fresh water organisms are provided in references (*30-33*). These references show a wide variation in the concentration factors for specific radionuclides in the same media. Environmental circumstances can greatly influence these factors and it may be advisable to determine their values prior to operation of the facility through the use of stable element analysis or fallout activity for the specific environment being monitored.

The calculated or measured concentrations

form the basis for dose calculations. Guidance and models for internal radiation dose calculations based on concentrations in air, water, and food are provided in ICRP-II (*18*).

The Federal Radiation Council (FRC) in Report Nos. 2 and 5 (*34*, *35*) provide specific guidance for relating population dose to intake of iodine-131, and strontium-89 and -90. Peterson and Smith (*28*) provide models for calculating thyroid dose from iodine-131 and -133 based on environmental measurements and on guidance in FRC reports. A simple method for estimating dose from radionuclides in air and water is to compare the measured or calculated concentration of individual radionuclides in air or water to the respective maximum permissible concentrations (MPC) as provided in ICRP-II. The ratio of the concentration to the MPS is then multiplied by the dose represented by the MPC to obtain the dose due to the concentration measured or calculated. For the nuclides iodine-131, strontium-89, and strontium-90, one should multiply the ratio of the intake rate to the Radiation Protection Guide (RPG) intake rate (*34*) times the dose represented by the RPG intake rate. These methods may provide conservative estimates of dose because the MPC's and RPG's are based on constant intake rates until equilibrium is reached or for 50-year continuous exposure.

However, the error introduced by the assumption of long-term exposure is probably very small compared to errors due to variable intake and uptake factors among individuals in the population and the inaccuracies in measuring or calculating representative environmental concentrations.

One potential exposure pathway is direct radiation from gaseous plumes and, in particular, isotopes of the noble gases krypton and xenon. Kahn et al. (*1*) and Russell (*36*) provide calculational techniques and models for estimating dose from exposure to an infinite cloud containing radionuclides of krypton and xenon. Similar information for krypton-85 is provided by Kirk (*13*).

Blanchard et al. (*37*) have demonstrated several of the above techniques in calculating population dose in the vicinity of Dresden Nuclear Power Station. These calculations were based on radionuclide discharge data collected by Kahn et al. (*1*) at the Dresden site.

Most of the published models are presented as mathematical models as opposed to computer models. However, some of the models have been computerized by operators or suppliers of nuclear power facilities for application around specific facilities.

Fletcher (*38*) describes the Hanford Engineering Regional Model for Environmental Studies (HERMES). This model is designed to calculate radiation dose occurring within a study area in a given year based on radionuclide releases. In its present form the model is large and complex. The major portions of all modules of the HERMES model are written in FORTRAN-V language and codes for the various modules are included as appendices to the report.

Soldat (*39*) describes a computer model which calculates total annual radiation dose and 50-year dose commitments to several categories of persons at population centers and combines these calculated doses into integrated (man-rem) annual and 50-year doses for large populations. This model includes a subroutine which calculates radionuclide concentrations in a variety of foods at time of harvest from concentrations in air, irrigation water, and soil.

Several government agencies have computer models for calculation of environmental concentrations and dose either operational or under development. These include EPA, AEC and the Tennessee Valley Authority. Many State agencies are developing computer capability to process, store, and report environmental radiation data. These data will be used in models for dose calculation.

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