A general guide for public health workers interested in the technical aspects of nuclear reactors and the scope of environmental surveys

Surveillance of Nuclear Power Reactors

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THE RECOGNITION that nuclear powerplants are competitive with fossil fuel plants and contribute to the control of air pollution holds great growth potential for nuclear power. The nuclear powerplant, however, possesses the potential for contamination of the environment with radioactivity. Consequently, State and Federal agencies responsible for public health protection are increasing their understanding of the technical aspects of nuclear reactors and of the surrounding environment in order to plan surveillance programs needed to assure the continued protection of the public's health.

The authority and responsibility for regulating nuclear reactors is assigned to the U.S. Atomic Energy Commission. In planning a nuclear plant, the group proposing the facility, or its contractors, sets forth a series of technical reports on the design and operating characteristics, particularly those related to safety.

These reports, called Design Safety Analyses, are reviewed in detail by the Division of Reactor Licensing of the U.S. Atomic Energy Commission and by its Advisory Committee on Reactor Safeguards. At the same time, other Federal and State agencies responsible for public health protection from radiation sources review the reports.

This paper is intended as a general guide for people engaged in State, county, and local public health activities. It describes the basic operational and design characteristics of nuclear power reactors, with emphasis on the public health aspects. Important areas discussed include potential releases to the environment under normal and accident conditions and the surveillance procedures required to keep abreast of the environmental implications of such releases.

Nuclear Power Industry

A rapid expansion of the nuclear power market began in 1965. In 1965 alone, eight reactors with a capacity of 4,870 megawatts electric (MWE) were ordered by utility companies. During 1966, 21 reactors with a total capacity of 17,200 MWE were ordered. In the first 6 months of 1967 contracts were submitted for 22 more reactors, with a total capacity of 17,215 MWE. Because of the unexpected volume of recent orders and commitments, the Atomic Energy Commission has increased its predictions to a level of 120,000 to 170,000 MWE by 1980.

Several factors responsible for this increase in nuclear powerplants are as follows: (*a*) recognition that nuclear power is now competitive with fossil fuel for producing electric power, (*b*) the utility companies are accelerating their plans for new plants to allow for the longer lead

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time necessary to construct a nuclear plant and put it into operation, and (*c*) an increased demand for electricity in the United States.

Planning and Review of Powerplants

AEC regulatory review. The AEC safety review and licensing procedure provides an analysis of each proposed reactor to insure that its construction and operation at a particular location will not produce undue hazard to the health and safety of the public. The responsibility for establishing this regulatory review stems from the Atomic Energy Act of 1954.

The primary element in the safety review of each reactor is the analysis conducted by the staff of the Director of Regulation. Licensing of a reactor facility is accomplished in two major steps. The first step is to issue a construction permit, and the second, after construction is completed, is to issue an operating license.

The analysis made by the AEC places great emphasis on the accident situation in which significant hazards to the public are possible. Accordingly, the information submitted in the preliminary Safety Analysis Report must be sufficient to allow analysis of accident situations, including a postulated accident of extreme severity requiring proper functioning of the containment and the engineered safeguards.

The information supplied by the applicant varies according to the reactor and its design features as related to a specific site, but it usually falls into the following four general categories: (*a*) characteristics of the reactor, (*b*) characteristics of the site and environs, (*c*) design criteria for the containment and the engineered safeguards, and (*d*) analysis of accidents.

After the AEC's regulatory staff has completed its review, the staff report is submitted to the Advisory Committee on Reactor Safeguards for independent review. This committee reviews the application and the staff report and makes a recommendation to the Atomic Energy Commission on the operation of the reactor as it relates to health and safety.

A prehearing conference is held by the parties involved to establish the procedures to be followed during the public hearing and to reach agreement on the major issues. The parties to the hearing are the Atomic Safety and Licensing Board, the applicant, the AEC regulatory staff, and any intervenors. The Atomic Energy Commission's Rules of Practice appear in title 10, "Code of Federal Regulations," part 2, in which the details of the hearing, the prehearing conference, and the rules regarding participation are presented.

Before issuing a construction permit, the Commission holds a hearing at a location near the proposed reactor site. This hearing is conducted by the AEC Atomic Safety and Licensing Board, which appraises the adequacy of the regulatory staff's safety review, examines again the general sufficiency of technical and other information supplied by the applicant and other parties, and adjudicates any controversy expressed in contested cases. After the hearing, the board recommends that the Atomic Energy Commission issue or deny a construction permit.

In the second stage of licensing, the applicant submits a final Safety Analysis Report for review by the AEC regulatory staff. If, upon completion of this review, it is determined that the facility can operate without undue hazard to the health and safety of the public, a notice is published in the Federal Register of intent to license the reactor. The operating license becomes effective 60 days after such publication, unless an interested party objects to the action. If an objection is raised, an operation permit hearing may be held.

Role of State and local public health agencies. It is important that the health agency and the power company establish a working relationship during the planning stage of a nuclear powerplant. The health agency, together with other State and local agencies having official interests in the siting of nuclear plants (agriculture, conservation, water resources, zoning boards), can assist the utility company's planning staff considerably by providing pertinent information on laws, regulations, and health considerations. At least one State has established a powerplant site evaluation committee made up of representatives from several concerned State agencies. This committee reviews sites proposed by the utility companies for powerplants and gives its opinion as to their suitability from the States' viewpoint.

During the planning stages, the health agency should call the attention of the utility company to the following specific points: (*a*) the limitations and requirements that may be placed on the facility by the health and related agencies having jurisdiction, (*b*) the need for zoning requirements that will maintain the prospective sites in the condition existing when the facility was evaluated, and (*c*) the kinds of changes that might occur in the area—and possibly lead to restrictions on the facility—unless a system of zoning is established with the full cooperation of the agencies and communities concerned.

After the site has been selected, the utility company applies to the Atomic Energy Commission for a permit to construct the nuclear powerplant. Generally, the Commission gives the State a copy of the applicant's preliminary Safety Analysis Report. Often the utility company also supplies interested State and local agencies with these reports. The health agency should participate in the review of the plant design as it relates to public health to make certain that it is reasonably consistent with the assumptions on which the site was chosen. Questions of public health significance should be brought to the attention of the applicant.

After conducting its safety review, the Atomic Energy Commission announces the time of the public hearing for the proposed nuclear plant. Before this date, however, the health agency must decide on its role in the public hearing. It may choose to participate as an intervenor, or it may decide to make only a limited appearance at the hearing. An intervenor is allowed to cross-examine witnesses and is subject to examination by the other participants. A person making a limited appearance is entitled to present prepared testimony but may not cross-examine nor be cross-examined during the hearing. A prehearing conference of the participants precedes the public hearing. Only participants take part in this conference, although other interested parties may attend as observers.

Role of Public Health Service. According to a 1961 interagency agreement, the AEC Director of Regulation provides the Service's National Center for Radiological Health with copies of all the Safety Analysis Reports and amendments of the applicants. The Nuclear Facilities Section (NFS) within the Center reviews these reports.

The NFS review evaluates site suitability, plans for environmental surveillance, waste management practices, emergency plans, and the calculation of emergency exposures. During the preliminary review of the Safety Analysis Report, the appropriate State health officer is advised of the technical assistance and consultation services available to his staff from the National Center for Radiological Health.

For example, the NFS review pays particular attention to the design and operation of environmental surveillance programs in the area surrounding the facility. This review does not duplicate the work of the AEC regulatory staff, but attempts to evaluate those factors of particular interest to health agencies and to assist the State and local health agencies in learning more about the public health aspects of the use of nuclear power.

When review of the preliminary Safety Analysis Report is completed, a public health evaluation report is submitted to the appropriate State health agency. Any apparent design anomalies or specific technical deficiencies are promptly called to the attention of the AEC review staff. The Atomic Energy Commission then resolves the problems by discussion or correspondence with the applicant.

A continuing review of the reactor facility is conducted until the final Safety Analysis Report is submitted, whereupon a final evaluation is made of the public health aspects to assure that the reactor can be operated safely.

Operational Characteristics of Reactors

The power reactors currently being constructed by utility companies are mainly of the pressurized water or boiling water type (figs. 1 and 2). A reactor produces radionuclides by several mechanisms, but the bulk of the radionuclides are the fission products which remain associated with the fuel material. They remain with the fuel until removed chemically at a fuel reprocessing plant. The radionuclides that might cause problems in nonaccident situations are the minute fractions of fission products which do not remain associated with the fuel and, also, the activation products which occur in various reactor systems. Practically all of these materials will appear ultimately as radioactive wastes, which must be either contained or dispersed.

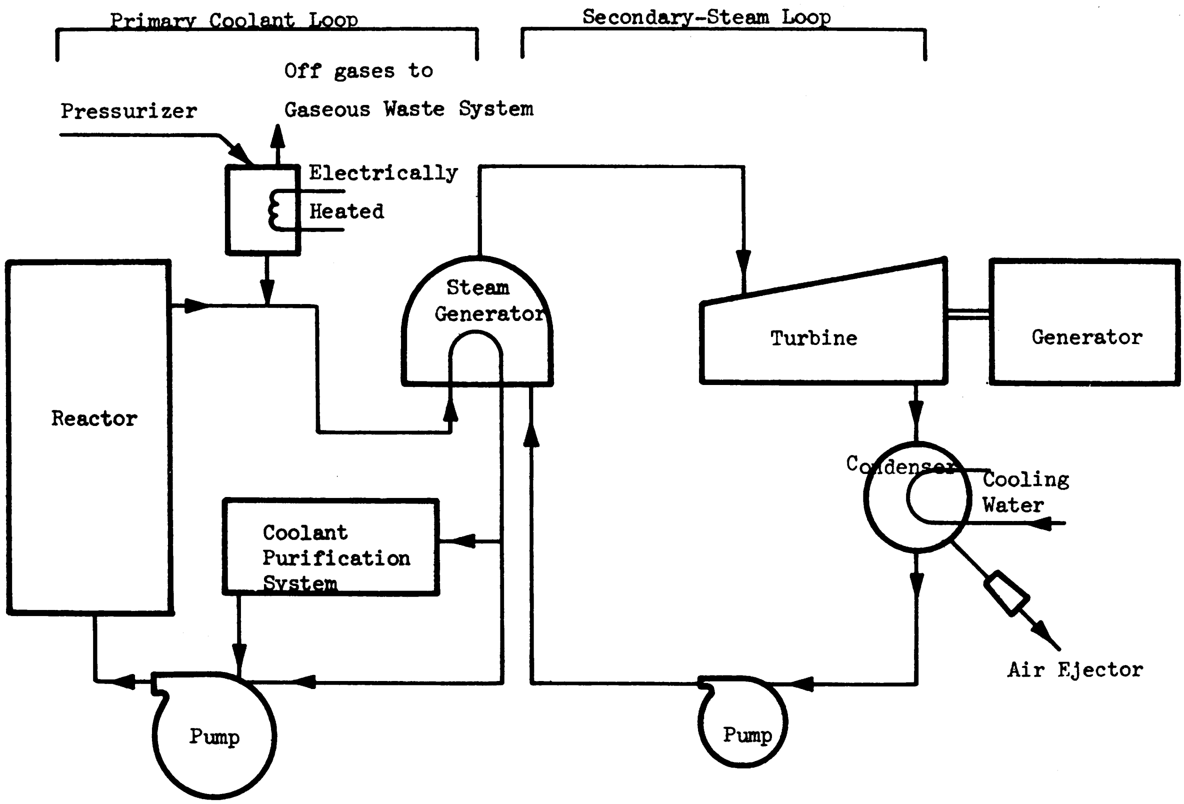


Figure 1. Flow diagram of pressurized water reactor

In a pressurized water reactor, the reactor coolant is circulated through the closed primary loop under high pressure (1,800–2,500 lbs. per square inch absolute) and, as in any circulating water system, some corrosion occurs on the surface in contact with the coolant. Since most of the surface exposed to the primary coolant in these reactors is stainless steel, the corrosion products are made up primarily of the constituents of stainless steel.

Two sources of activated corrosion products exist in the primary system. The most important one is the surface area located in regions of high-neutron flux such as the fuel cladding. But, also, surfaces located outside the high-flux region, such as those of the primary coolant piping, the steam generators, and the pumps, contribute corrosion products, which become radioactive as they pass through the high-flux region of the core. Defects in fuel cladding allow fission products to escape to the primary coolant, where they are accumulated. In a pressurized water reactor, the primary loop transfers its energy (heat) to the secondary system, usually a closed loop, which contains the turbine-generator. A bypass loop within the primary loop provides continuous purification of the primary coolant.

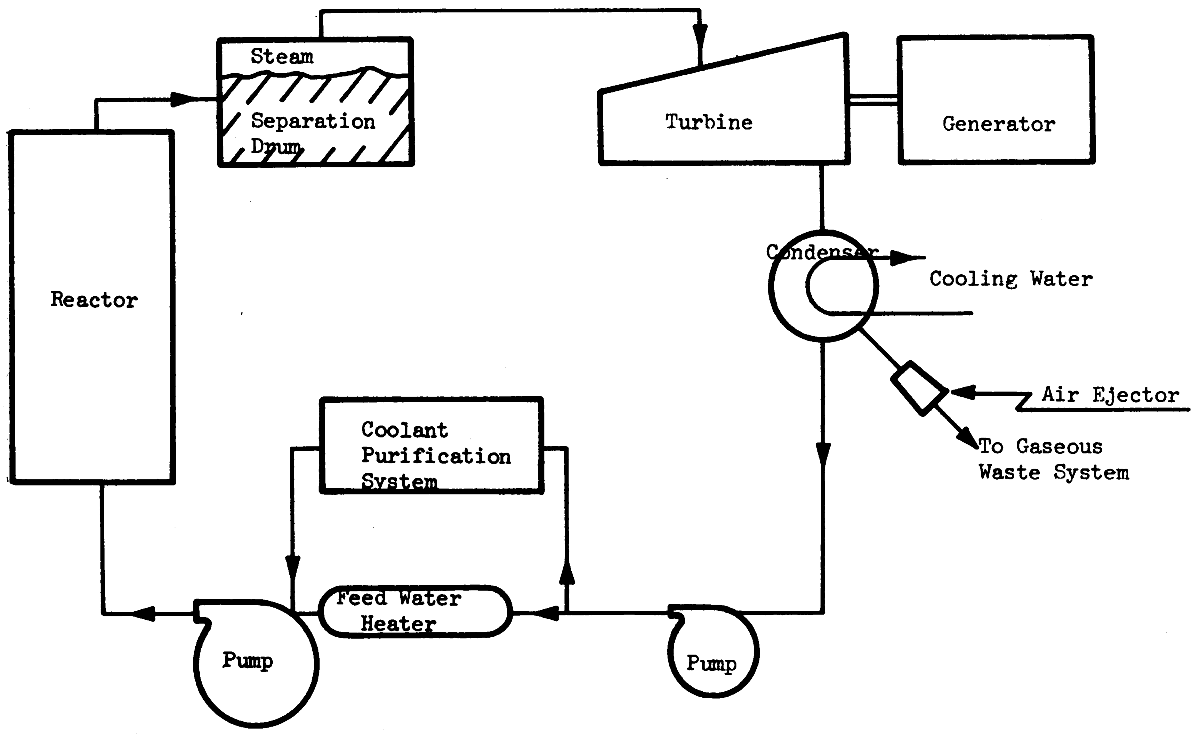


Figure 2. Simplified flow diagram of direct cycle boiling water reactor

The boiling water reactor operates at the same temperature as the pressurized water reactor, but the lower pressure at which it operates allows boiling to occur in the reactor core. The boiling water reactor normally has a direct-cycle system (but no secondary system) employing steam-separation equipment. The steam may be used directly to drive a turbine, or a superheater may be used to produce better steam conditions.

The radionuclides generated in a boiling water reactor are similar to those generated in a pressurized water reactor. The gaseous wastes are significantly different, however, because the radionuclides are retained in the coolant system for a shorter period. The steam formed in this type reactor contains the radioactive gas and passes directly to the turbine. The steam condenses and the noncondensable gases exhaust through the main condenser air ejector to a holdup system before being discharged through a stack. Controlled leakage around the turbine seals also carries radioactive gases into the waste system.

The radiogases derive from fission products and activation of gases in the system. The fission gases consist of the noble gases krypton and xenon and may include the halogens bromine and iodine. These fission gases appear in the coolant because of fission of "tramp" uranium in the system or failure of the fuel cladding to contain them. The principal activation gas in terms of total activity present is usually radionitrogen, which decays with a half-life of a few seconds and therefore has no waste-disposal significance. The activation of argon, which comprises about 1 percent of the volume of normal air, creates another radiogas. The argon which is activated can be present in air used to ventilate portions of the reactor cavity and in air dissolved in the coolant.

Table 1, adapted from a report of the Food and Agriculture Organization of the United Nations (*1*), shows the fission products which, because of their yields, half-lives, and biological properties, are important from the standpoint of environmental contamination. Table 2 presents information on the biological properties for a number of these nuclides, as well as for certain products which are either naturally occurring, arise through neutron activation, or may be produced in reactor fuels.

Environmental Surveillance

Because of the increase in use of nuclear power, both State and Federal public health agencies are increasing their responsibilities for technical review and surveillance of nuclear powerplants and other nuclear facilities. A number of these agencies have already had considerable experience in the types of environmental surveillance programs required in the vicinity of nuclear facilities. Experience gained over the past 15 years by the National Center for Radiological Health and by various States has provided the technical basis for a system of guidance for establishing surveillance programs in the environs of nuclear plants.

The guidance for environmental surveillance of nuclear facilities, summarized subsequently, applies only to areas outside the facility's site perimeter or fenced area, normally considered as the plant environs or "offsite" area. These programs provide a continuing examination and evaluation of the environment necessary for the assurance of the health and safety of the public.

Objectives. The prime purposes of environmental surveillance programs for nuclear power stations are as follows: (*a*) to verify the continuing adequacy of source control, (*b*) to provide data to estimate population exposure, and (*c*) to provide a source of data for public information. The provision of adequate source control is a responsibility of the nuclear facility operator, whereas assurance of public health protection is a responsibility of the local, State, and Federal agencies. The environmental surveillance program may be conducted by either the health agency or the facility operator on a cooperative or unilateral basis. If, however, the operator conducts the surveillance program, it

Table 1. Fission products [1] important because of their yield and half-life (atom yield >0.5 percent; half-life >10 hours)

Chain mass number	Fission yield [2] (atom percent of chain)	Nuclide and half-life	Total activity (kCi/MW)[3]
85	0. 3	Kr, 10.6 years	0. 2
89	4. 6	Sr, 51 days	39
90	5. 1	Sr, 28 days-Y, 64.4 hours	1
91	5. 4	Sr, 9.7 hours-Y, 57 days	45
95	6. 3	Zr, 65 days-Nb, 35 days	53
97	5. 9	Zr, 17 hours	19
99	6. 1	Mo, 66 hours	40
103	3. 4	Ru, 40 days-Rh, 57 minutes	28
106	. 5	Ru, 1.0 years-Rh, 30 seconds	2
129	. 9	Te, 41 days	3
131	3. 1	I, 8.1 days	24
132	4. 0	Te, 78 hours-I, 2.3 hours	30
133	6. 3	I, 21 hours-Xe, 5.3 days	24
135	6. 0	I, 6.7 hours-Xe, 9.2 hours	4
137	6. 2	Cs, 30 years-Ba, 2.6 minutes	1
140	6. 1	Ba, 12.8 days-La, 40 hours	48
141	6. 0	Ce, 33 days	51
143	5. 0	Ce, 33 hours-Pr, 13.7 days	28
144	5. 0	Ce, 285 days-Pr, 17.5 minutes	26
147	2. 9	Nd, 11.1 days-Pm, 2.6 years	23

[1] References 1 and 2.
[2] Slow neutron fission of ^{235}U.
[3] Kilocuries (excluding daughter activity) of fission product produced per megawatt of energy after operating a nuclear reactor for 1 year followed by 1 day of decay.

Table 2. Biological properties of some radionuclides of importance in environmental surveillance [1]

Radionuclide and source	Critical organ	Fraction [2] from gastrointestinal tract to critical organ	Effective half-life (days)
Fission products:			
^{131}I	Thyroid	0.3	7.6
^{133}I	do	0.3	0.9
^{135}I	do	0.3	0.3
^{132}Te	Gastrointestinal tract	(3)	(3)
^{137}Cs	Total body	1.0	70
^{89}Sr	Bone	0.2	50
^{90}Sr	do	0.009	6.4×10^3
^{140}Ba	do	0.03	11
^{103}Ru	Gastrointestinal tract	(4)	(4)
^{106}Ru	do	(4)	(4)
Rare earths [4]	do	(4)	(4)
Neutron activated:			
^{3}H	Body tissue	1.0	12
^{14}C	Fat	0.5	12
^{24}Na	Total body	1.0	0.6
^{32}P	Bone	0.37	14
^{41}Ar	Lung		0.08
^{55}Fe	Spleen	2×10^{-3}	390
^{59}Fe	do	2×10^{-3}	42
^{60}Co	Total body	0.3	9.5
^{65}Zn	Liver	0.035	66
Miscellaneous [5]	Gastrointestinal tract	(3)	(3)
Naturally occurring:			
^{226}Ra	Bone	0.04	1.6×10^4
^{228}Th	do	7×10^{-5}	690
Transuranic elements: ^{239}Pu	Lung		[6] 365

[1] Reference 1.
[2] Assuming that the radionuclide occurs in soluble form.
[3] Only an extremely small fraction is absorbed into the body from the gastrointestinal tract; therefore, the dose received by this tract during passage of the radionuclide is the limiting consideration.
[4] Rare earths ^{141}Ce, ^{144}Ce, ^{143}Pr, ^{147}Nd, ^{147}Pm, and including ^{91}Y and ^{95}Zr.
[5] A miscellany of other activation products such as ^{51}Cr, ^{54}Mn, ^{56}Mn, ^{58}Co, ^{64}Cu, and ^{65}Ni may be present.
[6] Reference 3.

may be desirable for the health agency to spot check his results by periodically analyzing duplicate samples. The surveillance guidance described here pertains to the operation of nuclear installations under normal operating conditions and is not intended to apply to an accident situation. A special preplanned emergency surveillance system would be required to adequately assess the public health hazard in a major accidental release of radioactivity to the offsite area.

Basic environmental surveillance requirements. The extent of surveillance required depends on the nuclear facility's location (population density, meteorological conditions, and other environmental factors), design, use, power rating, and mode of discharging radioactive waste. A health agency's review of the plantsite environment and of the facility's radioactive waste discharge system should include an assessment of the specific radionuclides anticipated in the normal discharges and the public health implications of the presence of these radionuclides. An investigation of the site environs is necessary to determine the number of people living in the vicinity of the nuclear plant and to identify those potential vectors that would result in radiation exposure. Exposure of this population group can result from direct external radiation and from intake of radioactive material into the body through ingestion and inhalation. Use of this basic information will make it possible for the environmental surveillance program to direct its efforts at sampling the most sensitive or critical vectors and thus obtain the data needed to evaluate source control and to estimate population exposure.

Planning for these surveillance activities therefore requires a knowledge of the purpose and extent of the program. It should also include a determination of the surveillance data which can be obtained from other sources, the type and accuracy of the obtainable data, and the resources and facilities available for supplying additional information. The operator's Safety Analysis Report submitted to the Atomic Energy Commission provides a major part of the required information. Local, State, and Federal agencies responsible for water supply and pollution control, agriculture, census, and conservation can often provide much of the additional information needed.

Preoperational environmental surveillance. In designing an environmental surveillance program, it is important that there be a preoperational survey of the most sensitive vectors. The information obtained will provide baseline data on environmental transport of radioactivity for a number of purposes. Among these are (*a*) an early indication of any increase in the amount of radioactive material released to the environment by the plant after initial startup, (*b*) a demonstration of the feasibility of the surveillance system for providing useful data, including sensitivity and suitability of the detection equipment, (*c*) training and experience for the personnel conducting the survey, and (*d*) to provide a mechanism for gathering data for public information.

The sampling locations and the frequency of sample collection of air, water, food, and agricultural products in the vicinity of the nuclear facility should be selected on the same basis as planned for the operational phase. Generally, preoperational surveys are conducted to obtain at least 1 year of reliable data before the initial startup of a nuclear installation.

Operational environmental surveillance. The data gathered by the operational environmental surveillance system must provide the basis for source control and estimation of population dose. Source control data for a given installation pertaining to releases of liquid and gaseous radioactivity should be provided to the health agency by the operator so that the relationship between radioactive discharges and the environmental surveillance data can be established. An environmental analysis, coupled with an evaluation of potential contaminants, enables the health agency to determine the possible routes of contaminants or vectors from the source to the population and to plan an appropriate surveillance system in respect to the required sampling location, frequency of sample collection, and necessary laboratory analyses. Because air and water are pathways through which radioactive contaminants are carried to other segments of the environment, such analyses represent a primary step in all surveillance procedures.

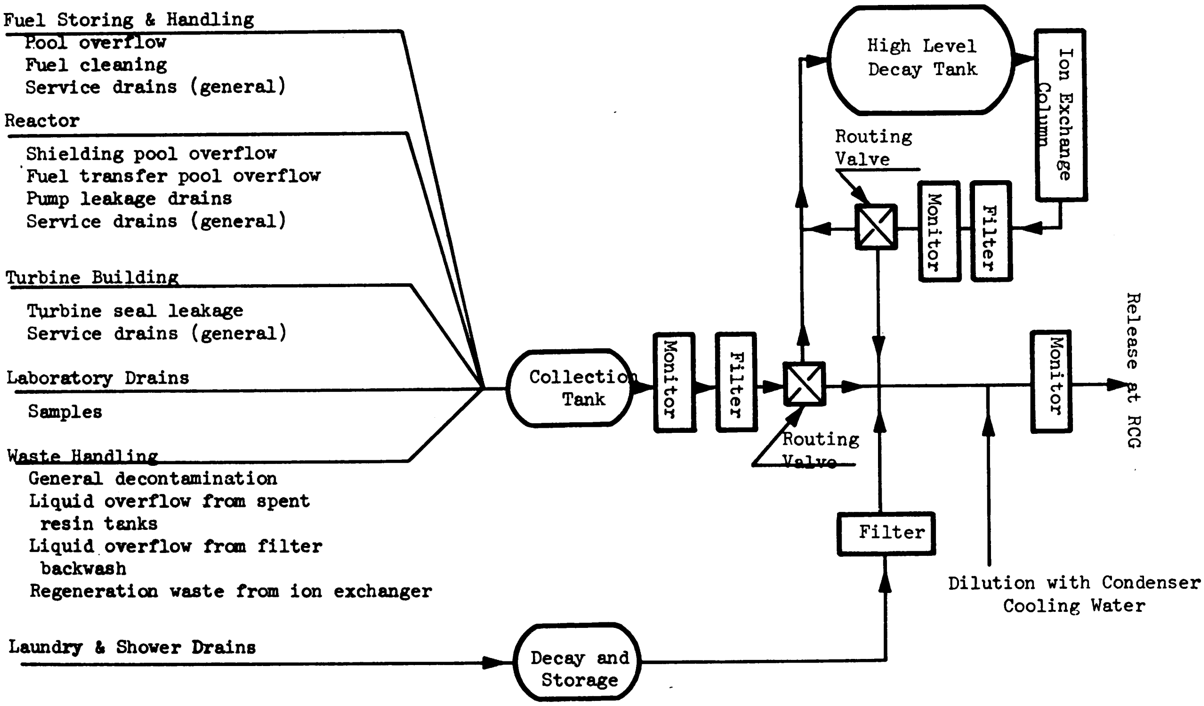
In establishing these surveillance operations, it is important for the planning agency to know the types and quantities of radioactive wastes that the nuclear plant would be expected to release under both normal and abnormal operations.

Releases to water environment. Although power reactors have a large fission product inventory within the core after a period of operation, they discharge only small amounts of radioactivity to the environment during normal operations. This favorable condition is the result of well-designed containment features supported by adequate waste-treatment systems.

Both fission and activation products are produced in reactors. Fission products, even though primarily contained within the fuel cladding, are also present in the primary coolant (in the range of microcuries per cubic centimeter). Their presence in the coolant is due to minute quantities of uranium contamination on the fuel and core structure, to cladding leaks, and to diffusion through the cladding.

The principal fission products that may enter the waste system include ^{89}Sr, ^{90}Sr, ^{137}Cs, ^{106}Ru, ^{144}Ce, ^{131}I, and ^{3}H, among others. The use of boron compounds in the water of primary reactors for normal reactivity control also results in the formation of ^{3}H. Activation products result from neutron activation of structural materials in the reactor core and subsequent corrosion or from the corrosion of primary system materials and their subsequent transport to the core area, where they become irradiated. Some of the primary activation products that may enter the coolant through corrosion and erosion are ^{58}Co, ^{60}Co, ^{54}Mn, ^{59}Cr, and ^{65}Zn.

Figure 3. Liquid waste system of a power reactor



Experience with nuclear powerplants to date has shown that careful waste-management practices, engineered safeguards, and proper operating procedures usually result in a minimal release of radioactivity to the environment. Liquid wastes may result from many operations at a facility, but are handled by one of the following five general methods or by a combination of these methods: storage for decay, filtration to remove particulate activity, ion-exchange or demineralization to remove dissolved activity, distillation to reduce the stored volume, and dilution of effluents. Laundry and shower wastes are usually of high volume and low contamination and are treated separately because detergents interfere with the operation of ion-exchange columns found in most waste-treatment systems. High-level wastes generally are stored without treatment. In-line monitors or radiochemistry analyses ordinarily are used to determine the necessary routing and disposal of liquid wastes in continuous processes.

Figure 3 shows the major sources and means of disposal for liquid wastes. If liquid wastes do not meet discharge criteria as set forth in title 10, part 20, appendix B, table 2 of the "Code of Federal Regulations," they may be held for decay, diluted with water (usually condenser cooling water), or purified by demineralizers. To assure compliance with these criteria, plant operating procedures include the monitoring of wastes to determine necessary routing and treatment before discharge.

Discharges of liquid radioactive waste into surface waters are usually more readily predictable than are gaseous releases into the atmosphere, and discharges into streams are usually more predictable than those into estuaries, large rivers, and impoundments. The primary concern over radioactivity in surface water is twofold. A fraction of the radioactivity will be in the dissolved state and, therefore, may not be removed by conventional water treatment processes; thus, it can reach man through domestic water used for drinking or culinary purposes. Another fraction, in either a suspended or dissolved state, may find its way to man through the food chain if fish or shellfish from these waters are used for human consumption or if the contaminated water is used for irrigation of food crops. The contaminated water might also be used extensively for recreational purposes, and such use may be considered another possible exposure mechanism from the source to man.

Surface water. The following pertinent factors should be reviewed and evaluated when surveillance of surface water is being established. These factors will establish the basis for determining the type, number, frequency, and location of sampling points.

1. Solubility characteristics of radioactive wastes that might be present in the receiving waters of the facility (suspended, dissolved, or both).

2. Downstream uses (public water supply, industrial, irrigation, recreational, fishing, and harvesting of shellfish).

3. Characteristics of the receiving waters (including velocities, mixing potential, and yearly discharge fluctuations).

4. Proximity to the facility of relatively quiescent bodies of water, such as reservoirs, in which dispersion characteristics may vary.

5. Thermal stratification of lakes and rivers.

6. Presence of a photography plant.

Water samples can be obtained by grab, continuous, or composite sampling. Grab sampling can be useful in determining the concentration at a given time and place. A composite sample, however, will represent a longer period and a larger body of water. Therefore, a composite sample is preferable when sampling streams or tidal waters. Gross analysis of these samples, which is easy to perform, provides some useful information, but specific radionuclide analysis is preferable because it is more meaningful.

Aquatic biota. Aquatic biota in the receiving waters of the facility's liquid waste discharge should be sampled extensively wherever there is commercial fishing or harvesting of shellfish. The seasonal changes in the habits of biota should be considered. Because shellfish can selectively concentrate a number of radionuclides normally found in the reactors' liquid effluent, they are sensitive indicators of the concentration of these radionuclides in water and should be sampled and analyzed to determine if the radionuclides exceed permissible concentration guidelines. Sometimes shellfish are the critical vectors for transporting the radioactivity from the liquid effluent, via the food chain, to man.

Sediment. The sampling and analyses of sediment frequently reveal the fate of a substantial fraction of the radionuclides in the liquid waste discharge from a facility. The radionuclides accumulate in sediment deposits, and during periods of flooding they can be reentrained, thereby causing relatively high levels of contamination in downstream waters. The sampling frequency varies according to the characteristics of a facility's receiving waters, the quantity of waste released within a given time, and the chemical and physical characteristics of the waste. Usually annual, semiannual, or seasonal samples are sufficient. Radioactivity data from sediment sampling yield little information of value for computation of the dose to the population.

Ground water. The need for monitoring ground water depends primarily on local geological and hydrological conditions and the method used by a nuclear facility for discharging radioactive waste. It has been established, based on geological and hydrological studies for licensing of low-level waste disposal sites, that most radioactive material moves at a very slow rate through geological formations. In places where the ground water may be contaminated by the liquid discharge from a nuclear facility, it should be sampled and analyzed for specific radionuclides to evaluate the potential health hazard. Sampling usually does not need to be more frequent than quarterly, and often annual samples are sufficient.

Releases to the atmosphere. Gaseous fission products are found in the primary coolant of a reactor as a result of leakage and diffusion through the fuel cladding and fissionable contaminants on the outside of the fuel elements. These radioactive gases present in the air effluent result from the waste treatment process, relief valve operation, air ejectors, or other mechanisms. To hasten the dilution and dispersion of airborne waste into the atmosphere, the waste is released from a nuclear reactor via a stack or an exhaust duct on the top of the containment structure. Releases of particulate or gaseous radioactive material, whether or not combined with inert local atmospheric particulates, are subject to physical and meteorological phenomena such as diffusion, sedimentation, inversion, and wind movement. Airborne radioactive waste may be deposited on soil or plant tissue, where it may cling or be metabolized through plants (above or below ground) and subsequently be absorbed in the tissue, fruit, or seed used for animal or human consumption.

Since radioactive wastes are discharged from reactor facilities, an environmental surveillance program for such wastes is highly desirable. In developing an air surveillance program, the health agency should consider the following factors.

1. Sampling should be based on evaluation of the meteorological conditions and the preoperational environmental surveillance data.

2. Detailed information should be compiled on population and land use—particularly agricultural use, such as dairy farming, in the environs of the facility.

3. The health agency should learn from the operator of the nuclear facility what information is being collected on the discharge of gaseous effluents.

4. Only airborne particulate activity can be collected by a pump (high- or low-volume) and filter method. The high-volume sampler, operating at approximately 50 cubic feet per minute, collects more activity per sample and produces greater sensitivity for a given sampling period than a low-volume sampler. High-volume samplers require considerable maintenance when operated continuously, but good sensitivity is obtained for sampling periods of a few hours; hence, the high-volume samplers are best used for occasional grab samples. The low-volume sampler is usually better for environmental sampling programs because it is less expensive to operate, is quiet, and may be run continuously for many months without maintenance. Several low-volume samplers produce flow rates up to 10 cfm and thus can collect sufficient samples for daily analysis if desired.

One of the more important groups of radionuclides that may be present in the gaseous effluent is radioiodine, which can exist in several different chemical and physical states. Radioiodine can be sampled by inserting carbon cartridges in the particulate sampler. Since the efficiencies of filters and carbon cartridges are based on elemental iodine and the efficiencies of the filters in removing different forms of radioiodine vary, collection of an atmospheric sample which is known to be representative of the radioiodine concentration in air is sometimes difficult.

5. The principal materials discharged to the atmosphere from a reactor are the radioactive noble gases. A difficult, but important aspect of environmental surveillance of a nuclear power station is monitoring for the noble gases using dosimetric devices, or the analysis of representative samples using cryogenic techniques. Film badges and certain types of ionization chambers have been used to monitor radiation doses from these noble gases released to the environment. More recently, the use of thermoluminescent dosimeters has been demonstrated to be an effective means of obtaining dose measurements around nuclear facilities. The National Center for Radiological Health is conducting studies on the use of these dosimeters.

Milk and crops. An environmental surveillance program should include collection of samples of milk and food crops within a distance of 10 to 15 miles of the nuclear facility. These distances may be several times farther depending on the quantity of waste discharged, meteorological conditions, and the particular characteristics of the environment related to potential exposure of the population.

The pastured cow is one of the best and most direct means for biosampling to determine radioiodine and radiostrontium levels in the environment under both normal and abnormal reactor operating conditions. Since the radioiodines released to the environment are concentrated in milk, sometimes they can be the limiting group of radionuclides in the stack effluent. Milk samples should be collected and analyzed weekly for radioiodine and composited monthly for analysis of ^{89}Sr and ^{90}Sr, except when there are accidental or abnormal discharges—at such times a more frequent sampling schedule should be undertaken. If stack-sampling data on iodine are available to the health agency, the frequency of milk sampling for iodine analysis could be decreased to bimonthly or monthly intervals. Periodic sampling of food crops or other vegetation may give supplementary indicative information.

The Federal Radiation Council has established guidelines for human intake of ^{89}Sr, ^{90}Sr, ^{131}I, and ^{226}Ra. The following three graded scales of action are recommended: (*a*) range 1, periodic confirmatory surveillance as necessary, (*b*) range 2, quantitative surveillance and routine control below the upper limit of the range, and (*c*) range 3, evaluation and application of additional control measures as necessary. The scales are based on the average intake for 12 months. Individual daily values, which may fluctuate widely from day to day, are of less concern. For fallout from nuclear weapons tests, the intake from ingestion of drinking water or from inhalation has been small in comparison to that from food. Such, however, may not be the case for wastes from nuclear facilities.

Soil. Soil samples should be collected annually in the area with the highest probability of deposition downwind from the reactor, preferably in the vicinity of sampled food crops. The samples then need to be analyzed to determine the accumulation of long-lived radionuclides (^{90}Sr or ^{137}Cs). Since these radionuclides are also constituents of stratospheric fallout, samples from the plant area should be compared with control samples taken from areas beyond the influence of the reactor.

Precipitation. Precipitation samples have limited value in an environmental surveillance program for a nuclear power station. Such samples are usually more indicative of the presence or absence of weapons or atmospheric fallout than of the radioactivity present in a reactor's stack effluent, although they may be of some value for baseline data.

Typical surveillance program. Table 3 outlines a typical program which can be used as a guide in developing an environmental surveillance program for a nuclear powerplant.

Planning for Radiological Emergency

Because of the potential hazards to the public, reactor designers must continue to exert extensive efforts to produce systems inherently safe

Table 3. Typical environmental surveillance program for a nuclear powerplant

Vectors or indices	Recommended surveillance program: Relative frequency of sampling	Analyses	Sampling locations
Surface water: receiving waters of the facility.	Continuous composite or weekly grab sample.	Gross beta and gamma scans. Periodic beta scintillation analysis for ^{3}H with frequency a function of the levels measured.	Stream above and below the facility; reservoir, bay, lake, nearest shoreline; any nearby domestic water suppliers using the receiving waters as a source.
Aquatic biota	Variable	Gamma spectrum analysis for selected radionuclides.	Near the reactor's outfall, or above and below if receiving water is a stream.
Bottom sediment	Semiannually	Gross beta and gamma scans.	Near reactor's outfall, or above and below the outfall if the receiving water is a stream.
Ground water	As applicable (usually quarterly or semiannually).	Gross beta and gamma scans.	Supplies within 5 miles of the facility.
Air	High-volume samplers daily on a ½ or ⅓ cycle. The dosimeters should be processed every 28 days.	Gross beta and gamma scans of filters and cartridges. Readings from suitable dosimeter devices.	See page 908.
Milk	Weekly (see page 909)	Gamma spectrum analysis for ^{131}I.	Dairy herds within 10 to 15 miles of the facility.
	Monthly composite	^{89}Sr and ^{90}Sr, or total Sr by beta analysis.	
Food crops and other vegetation.	Seasonal (before or at harvesting time).	Gamma spectrum analysis	Within a 10-mile radius of the facility.
Soil	Annually	^{90}Sr and ^{137}Cs or gross beta	Prevailing downwind direction in nearest agricultural area.

as well as to engineer safeguard systems which will minimize the possibility of reactor accidents. Engineered safeguards include the following: (*a*) normal controls designed to provide automatic shutdown of the reactor or to gradually lower the power whenever there is loss of power or excessive power and whenever there are unusually low or high operating pressures, insufficient cooling rates, high containment-vessel pressures, and high radiation levels; (*b*) a backup chemical shutdown system, which injects borated water into the primary coolant to effect reactor shutdown by the absorption of neutrons; and (*c*) a high-integrity containment structure that is designed to limit leakage to the atmosphere to a small percentage of the contained volume per day. Other engineering safeguards are included to further limit the probability of accidents and their consequences.

Certain safeguards are also inherent in the reactor design. Pressurized and boiling water reactors, because of their negative temperature coefficient, are inherently capable of limiting any accidental increase in the power level; that is, any increase in the temperature of the core will be accompanied by a decrease in the fission rate.

Since the bulk of evidence indicates that reactors are relatively safe, why should public agencies and nuclear power reactor operators be concerned about emergency planning? There are several reasons, including the following: (*a*) although the probability of an accident is extremely low, the consequences might be severe; (*b*) more and more power reactors are being planned and built; (*c*) their power levels have greatly increased, increasing the accumulation of fission products and thus the potential hazards; (*d*) reactor sites are being selected closer to urban areas, and (*e*) the large number of people who might be affected by a nuclear accident. Consequently, it is desirable for operators of nuclear power reactors to prepare emergency procedures. In the event of accidental release of radioactivity, these measures can be immediately effected to minimize the hazard to both the general public and to the plant personnel.

Types of accidents. The hazards of nuclear power reactors are principally associated with major accidents rather than with normal operation. Accidents may result during operation or maintenance from excessive increases in reactivity, improper handling of fuel, sticking of the control rod, failure of the coolant pump, and other causes; these accidents are subordinate to, or may lead to, the maximum credible accident (MCA). Therefore, the Safety Analysis Report usually focuses on such accidents.

Generally, the type of accident considered to be the most severe from a public health standpoint is that in which fission products are released to the atmosphere. Such releases include iodines, other halogens, noble gases, and numerous other radionuclides. These accidents are postulated and analyzed in the reactor's Safety Analysis Report. As part of their overall radiological health responsibilities, health agencies should incorporate planning for reactor emergencies in their program activities.

Nuclear reactor emergency plans. Many administrative and technical problems are associated with the development of a satisfactory emergency plan for a nuclear facility. Such a plan must be a cooperative effort between the reactor operator, health agencies, and other interested agencies.

The emergency plan of the reactor operator should provide for (*a*) sufficient instrumentation, both onsite and offsite, to detect an emergency condition quickly; (*b*) procedures to evaluate and determine the extent of contamination exposure so that spread of the contamination can be rapidly limited; (*c*) decontamination procedures, movement of people, and medical care; and (*d*) a system for the notification of the appropriate AEC officials and public health authorities. Personnel must be designated who can initiate the emergency plan promptly, both inside and outside the plant. The operator must evaluate and periodically test monitoring systems to determine if, under accident conditions, they will provide the technical data necessary to estimate quickly the direction of the release plume and the magnitude of the resulting problem so that responsible authorities can be notified immediately. The resources of the community, in terms of equipment, facilities, and manpower, must be ascertained; an assessment must be made of the resources needed from outside the community and arrangements made for obtaining them.

Being aware of the available resources is extremely important because in some areas the technical personnel with the expert radiation knowledge who could assist in evaluating the problem might not be near the facility. Although the experts would be required to handle onsite problems, initially technical assistance might have to come from the reactor's personnel until technically qualified persons arrive from outside the community, either from a State or local health agency, the Atomic Energy Commission, or the Public Health Service.

Public health agency emergency plans. The extent of a health agency's involvement in emergency planning depends on the contamination that might arise from an accident and the effect of that contamination on the public's health. Development of an adequate plan is a complex matter requiring the cooperation and coordination of many agencies. Health agencies are ideally suited to assume leadership in this aspect of radiological health. The degree of their participation calls for mutual agreement between the reactor operator and the health agency.

The health agency should initiate liaison with the operator of a nuclear powerplant during the preconstruction permit stage. During the early planning phase, the agency should evaluate resources available for emergencies, including the police and emergency crews, radiation monitoring capability, communications, medical facilities, transportation, and laboratory capability necessary for expanded radiation surveillance.

Cooperation of the facility's management is required in preparing detailed, written procedures for use at the reactor from the start of power operation. Based on the knowledge obtained from the preliminary studies, State plans should be formulated which coordinate the plan for each specific reactor with the available community resources and the State, local, and Federal agencies, including the radiological assistance capabilities of the Atomic Energy Commission and the Public Health Service. It may also be necessary to coordinate the plans with those of the authorities in adjoining States. After reactor startup, the facility operator and health agencies should periodically conduct joint tests of the emergency plan.

REFERENCES

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Construction Grants for Rehabilitation Centers

Four grants totaling approximately $474,000 were made by the Vocational Rehabilitation Administration, Department of Health, Education, and Welfare, to help States expand and improve their rehabilitation facilities for disabled people. The Federal share of a construction project, under a formula in the Federal law, varies from 33⅓ to 66⅔ of total costs apportioned according to each State's population and per capita income. These Federal grants are to be used to help pay for constructing new rehabilitation centers and workshops, for purchasing existing buildings, for expanding and altering facilities, and for purchasing land and equipment.

The first four grants were made to the following institutions: North Central Alabama Rehabilitation Institute, University of Alabama Medical Center, Birmingham, $100,000, for establishing a vocationally-oriented rehabilitation center; Rehabilitation Institute of Kansas City, Mo., $81,412, for a new building closer to medical facilities with inpatient beds; Williamsport Rehabilitation Center, Williamsport, Pa., $250,000, for a new building with comprehensive rehabilitation services; and Utility Workshop, Denver, Colo., $42,500, for a building to replace the present building.