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ENVIRONMENTAL SURVEILLANCE OF A
NUCLEAR FACILITY⁽¹⁾

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ENVIRONMENTAL SURVEILLANCE OF A NUCLEAR FACILITY

J. K. Soldat and C. M. Unruh

I. Introduction

Any facility which utilizes radioactive materials in manufacturing, process control, research or medical applications has a potential for releasing such material to the environs. Normally those facilities which handle only sealed sources or small quantities of radionuclides, such as radiographic work, hospitals or educational institutions, have an insignificant potential for environmental contamination.

Simple accounting procedures and in-house programs for careful use and safe storage of radionuclides are usually sufficient for protection of the employees, patients and public from inadvertent exposure.

Facilities which have a significant potential for environmental contamination and hence require some degree of environmental surveillance include: nuclear fuels manufacturing and reprocessing plants, nuclear power reactors, plants for separation and purification of radionuclides, and so called Hot Laboratories handling large quantities of unsealed radioactive materials.

Such facilities will normally have process controls and equipment designed to control the release of radioactive material to the environs and provisions for monitoring of the liquid and gaseous effluents. Depending upon the nature and quantities of radionuclides being released an environmental surveillance program around such facilities may range in complexity from simple confirmation of the effluent monitoring results up to a complex network of field measurements, sampling and laboratory analysis.

Several recent symposia have been directly or indirectly related to the subject of environmental monitoring at nuclear facilities⁽¹⁻⁴⁾.

In addition, several excellent books, reports, and pamphlets have been written about methods and equipment for routine and emergency environmental surveillance, and radiochemical analysis⁽⁵⁻¹³⁾.

II. Objectives of Environmental Surveys

Several objectives often stated for environmental survey programs are listed in Table I.

Table I
Purposes of Environmental Surveys⁽¹⁴⁾

1. Radiological Protection of People
2. Fulfill Regulatory Requirements
3. Audit Containment Systems and Effluent Monitoring
4. Maintain Public Acceptance of the Nuclear Facility
5. Legal Protection from Liability Actions

The primary consideration should be radiological protection of the public⁽⁹⁾. Secondary reasons are fulfilling regulatory requirements, auditing containment systems and effluent monitoring results. These latter two reasons are, however, related to the primary objective since the purpose of regulatory requirements is primarily radiation protection. Two others often mentioned as secondary objectives are both related to public

relations--maintaining public acceptance of the nuclear facility and gathering of data for protection against liability claims. In nearly all instances an environmental survey program designed around the primary objective of radiological protection will either satisfy the other objectives or can be made to satisfy them with only slight additions and alterations.

Overly elaborate environmental monitoring programs are not only economically unsound but excessive sampling and measurement in the environs might arouse unwarranted fears in the public.

In the early days of the atomic energy program it was not always possible to relate the environmental monitoring data to a parameter that could be used to express actual population risk. Early programs consisted of sampling and analyzing environmental media, seeking for radioactivity and attempting to explain its presence there. Today it should be possible to relate radioactivity in the environment to radiation exposure of people and thus to evaluate the impact of a nuclear facility in terms of the radiation dose received by residents in the vicinity of the plant⁽¹⁴⁻¹⁵⁾.

III. Development of the Environmental Surveillance Program

If the objective of the surveillance program is to ensure that acceptable doses are not exceeded, measurements must be made which will allow tissue doses to be calculated. It follows that the most profitable measurements will be those which can be made on the materials which provide a direct source of exposure, whether air, water, food or some other material. In certain cases, however, measurements on materials, which do not constitute a direct source of exposure to man but which are good indicators of environmental contamination, can be used to evaluate the trend of this contamination⁽⁹⁾.

Development of the surveillance program must start with the facility itself, work through the environmental and population factors operating between the points of release and the points of public exposure, should consider the potential radiation doses to the public, and then should come full circle back to the facility by relating public exposure to specific release rates of the various radionuclides involved. Table II illustrates the evaluation of radiation dose and the related environmental measurements⁽¹⁶⁾.

The first column in the table lists five principal steps in the process, the second column lists the factors to be considered at each step, the methods of evaluation are given in Column 3, and the last column indicates the standards against which the results of the evaluation are to be compared.

Step A requires a thorough knowledge of the facility itself-- what processes are involved? What radionuclides are to be released routinely and in what quantities? How are they to be released? What is the potential for accidental release of additional radionuclides or of greater quantities than normal? Are the methods chosen for effluent monitoring sufficient to evaluate the potential impact of the routine releases in the environs? Will accidental releases be detected accurately and rapidly enough to permit proper environmental assessment and control?

Step B involves knowledge of the environment and the possible interaction of the environment with the released material. Studies of the meteorology, hydrology, and aquatic and terrestrial biology of the environs are required to determine the behavior of the particular chemical and physical forms of the radionuclides released. The behavior after release of course can be monitored by sampling of environmental media such as air, water, foods, soil and sediment.

Table II
Evaluation Chart - Environmental Population Dose (16)

<u>Step</u>	<u>Factors</u>	<u>Evaluation</u>	<u>Standards</u>
A. Release	Concentration Rate of Release	Measure Effluent	Release Guides
B. Dispersion, Reconcentration	Meteorology, Biology, Hydrology, Physical and Chemical Forms	Measure Environmental Media - Air, Water, Foods	Fraction of MPC or MPC (Concentration Factors)
C. Intake	Air, Concentration, Water, Consumption Food Rate	Diet Surveys, Studies of Uses of Environs	FRC Ranges, ICRP - $\mu\text{Ci/day}$
D. Retention	Percent Uptake, Biological Half-Life, Distribution in Body	Bioassay, Whole-Body Counting	M.P.B.B.'S
E. Dose	Body Dimensions, QF, DF, Rads/ μCi	Calculate Doses to- Maximum Individual, Population Average, Adult, Child	10-CFR-20, AEC Manual, FRC Reports, NCRP H.B.'S, ICRP H.B.'S

Step C is related to determination of the human factors which influence the impact of the released material. What are the dietary habits of the local population? What are the sources of their food? What recreational habits might affect their exposure? If data are not readily available to answer these questions, then special studies may have to be undertaken to gather them.

The last two steps, Steps D and E, normally involve only paper studies utilizing the data available from the previous steps. Using the parameters defined by the ICRP for the Stand Man (17) and the literature data on physiological parameters of other age groups, one can estimate the long-

term accumulation of radionuclides in the body from the intakes previously derived. Then the radiation doses can be calculated for comparison with the appropriate guides and standards. Confirmation of retention and accumulation of radionuclides in the body, when these represent a significant fraction of the maximum allowable amounts, can be made through in-vivo or whole-body counting of appropriate members of the general public.

Once these doses have been estimated one can proceed back up the last column of the evaluation chart deriving the maximum allowable releases of the radionuclides and establishing the relationship between actual release and potential doses to people. If it turns out that the releases are only a small fraction of those which would result in residents receiving the maximum allowable doses, then environmental monitoring can be limited for a few simple measurements of indicator materials which will confirm the effluent monitoring results.

On the other hand if the releases are such that the radiation doses received by the public will closely approach the limiting values, then a comprehensive program of sampling and analysis of air, water, foods, soil, and external dose rates must be instituted. The foregoing review in terms of radiation dose and the environmental and human factor influencing the behavior of the radionuclides should have identified the "critical" nuclides and "critical" pathways of exposure which must be monitored.

After an environmental monitoring program has been established it should be reviewed periodically to ensure that it has been properly formulated and that it still is meeting its objectives⁽⁹⁾.

Experience may have reaffirmed relationships between quantities released and environmental measurements, allowing for a reduction in the scope of the surveillance program, or the nature and quantities of radionuclides released from the facility may have changed requiring a shift in the emphasis of the environmental program.

Before we proceed with a discussion of more specific environmental monitoring programs I would like to amplify some of the items mentioned above in conjunction with Table II.

If we accept the thesis that environmental surveillance programs must be aimed principally around radiological protection and the results are to be evaluated in terms of radiation dose, then we must be familiar with the applicable dose limits and the pathways of exposure available in the environs.

IV. Radiation Guides and Standards

The International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurement (NCRP) have been active in the development of standards for protection against ionizing radiation for the past forty years. The Federal Radiation Council (FRC), whose functions were recently transferred to the new Environmental Protection Agency (EPA), was involved for over ten years. The recommendations of these groups have been used as the basis for the Atomic Energy Commission's (AEC) regulatory and health and safety programs.

Figure 1 illustrates the current radiation standards for the general public as spelled out by the FRC, and the AEC in Title 10 of the Code of Federal Regulations Part 20 (10CFR20). Two sets of limits are quoted--one for

controlling the exposure to an individual member of the population and the other for the average exposure to the general public. The whole-body limit for the general population can be derived from the recommendation that the dose to the gonads be limited to a total of 5000 mrem up to the mean reproductive age of 30 years.

The principal limit promulgated by the AEC for nuclear facilities has been the one of 500 mrem/year to the whole body of an individual. Because of the geographical location of nuclear facilities in relation to the surrounding populations, it is not feasible to imagine a situation where the average exposure to a significant number of people could approach the limit of 170 mrem/year.

The ICRP, in their publication 7⁽¹⁸⁾, have discussed environmental monitoring and have defined the critical population group whose radiation exposure is to be compared against the recommendations for the maximum permissible doses for individual members of the public. Their definition is -

"The critical group should be identified in such a way that it is representative of the more highly exposed individuals in the population and is as homogenous as practicable with respect to radiation dose, that is, with respect to those factors which affect the dose in the specific case considered."

V. Pathways of Environmental Exposure

The principal pathways by which radioactive materials released to the environs can reach and expose people are illustrated in Figure 2⁽¹⁹⁾. Included in this figure are the environmental parameters (Step B) and the human parameters (Step C) mentioned in Table II.

External doses can be received from exposure to the cloud of radioactive gases released from a nuclear facility, from swimming or boating in and on waters contaminated from liquid effluents, contact with ground or objects contaminated via deposition from airborne or waterborne radionuclides.

Internal exposure can result from inhalation of air or ingestion of water and foods containing the released radionuclides. The pathways by which the foods become contaminated from releases to air and water are also shown. For example, chickens could ingest radioactive materials with their drinking water, with insects, or with feed grown on contaminated ground or irrigated with contaminated water.

Detailed studies of the behavior of radionuclides in the several environmental media are not always available, but much is known at least in general terms about the most important radionuclides. Habits of the local population which might affect their radiation dose vary with each individual site and should be determined before the environmental survey is designed.

State and Federal agriculture, recreational, and fish and wildlife agencies can be of assistance in defining these parameters. Sometimes special studies of the local population are required, especially if specific critical pathways are involved. Examples of the latter include the consumption of Laverbread by persons in the vicinity of the Windscale facility in the U. K. (20), consumption of oysters in the vicinity of the Bradwell nuclear power station, U. K. (21) and the consumption of Columbia River fish harvested downstream of the AEC's production reactors at Hanford. These three examples are illustrated in Figures 3, 4 and 5.

Several population studies have been undertaken at Hanford in an attempt to better define the dose to those persons who eat large quantities of Columbia River fish and also to define other dietary and recreational habits affecting radiation doses.

These studies are listed in Table III⁽¹⁹⁾. Inspection of the items in this table indicate that the majority of them are connected with the Columbia River.

A further example of a detailed study of a critical pathway is afforded by the Clinch River Study⁽²²⁾ conducted in the environs of the Oak Ridge National Laboratory. The study included evaluation of the consumption rates of various foodstuffs containing long-lived radionuclides released to Clinch River via White Oak Creek.

VI. Environmental Surveillance Programs

A. Preoperational Surveys

The operator of a nuclear establishment is held responsible only for that radioactive material which the particular plant has added to the environment.

To assess his contribution it may be necessary to interpret the results of operational surveys in the light of pre-existing levels of radioactivity in the environment.

Other sources of environmental radiation and contamination are:

- (i) Naturally occurring radiation and radioactive materials;
- (ii) Fall-out from nuclear explosions;
- (iii) Nuclear establishments other than the operator's.

TABLE III
POPULATION SURVEYS AT HANFORD (19)

Date	Population Group and Survey	Group Size
1960- 1968	Plant employees measured with a Hanford whole-body Counter were asked to complete a diet survey form. A computer file of diet and whole-body counting data was prepared.(3)(4)	About 7000 persons
1965- 1968	Elementary school children (5-12) in 17 local schools were surveyed with a whole-body counter and a 7-day diet record card. About 75% of the students voluntarily participated in the survey. (4)	About 5500 children
1969	Teen-aged students (12-17) in a high school and a junior high school were surveyed with whole-body counter and oral diet and river recreation questions. About 50% of the students responded.	427 Teen-agers
1967- 1968	A statistically derived sampling program was used to obtain information on Columbia River fishing. Stretches of the river were visited for 4-hour periods according to a schedule derived from random selection, and the fishermen interviewed. (5)	2,132 Fishermen interviewed
1966- 1969	Whole-body counter and diet surveys were made of fishermen located at popular fishing spots on 4 occasions.	85 Fishermen
1969	A survey using the mobile whole-body counter and oral diet questions was conducted in a local rural area using Columbia River water for irrigation. Scheduling families to visit the whole-body counter became a community service project for 7 4-H Clubs in the area.	343 Persons
1969	Students in Home Econ. classes in 2 local schools assisted in a survey of eating habits of family members. They estimated the size of servings taken by family members during the course of 11 meals during a 1-week survey period using hand-books containing pictures of 5 weighed serving sizes for 25 different varieties of foods.	250 Persons
1970	A survey was conducted in 2 coastal communities located near enough the mouth of the Columbia River that Zn-65 from Hanford could be detected in local marine organisms. Both communities were centers for commercial seafood production.	462 Persons

Pre-operational measurements of radioactivity in the environment may occasionally reveal hitherto unexpected local environmental radioactivity from natural or other sources which could otherwise have been attributed to the operation of an establishment. Perhaps the most important function of a pre-operational survey is to train staff in sampling and analytical techniques (9). To do this, methods used in a pre-operational survey for radioactivity should be identical with those to be used in the routine surveys.

Samples of air, water, soil and plant and animal life should be collected and analyzed for those radionuclides which will be of interest when the facility becomes operational. In preoperational surveys around reactors, it may be sufficient to measure external gamma dose rates, gross beta or gamma activity in air, water, soil and biological materials. A few measurements for ^{90}Sr might be made to determine the contribution from fallout.

A preoperational survey around a complex nuclear facility operated by an AEC contractor should include all of the kinds of measurements that will be made after operations begin. Also included should be measurements of meteorological and hydrological parameters likely to effect the dispersal of released effluents. The survey should extend over a period of 12 to 18 months, and include two growing seasons. By the time the facility is operational, the particular vegetation, animals, water locations, etc., likely to concentrate released nuclides should have been indicated. Routine operational surveys can be designed on the basis of this information.

B. Emergency Surveys

These have to be carried out in situations where accidental releases of radioactive materials lead to significant contamination of the environs and/or high external dose rates. They are generally designed to define the area and extent of the contamination spread.

Detection of an accident will normally depend upon the usual procedures for discerning abnormal conditions within the establishment and its environs. Should an emergency occur the immediate aim must be to bring it under control, and to reduce to a minimum injury to people and damage to property. For this reason each installation should promulgate, in detail, specific standing arrangements appropriate to all conceivable accidents for which it is reasonable to plan. Clear lines of responsibility should be defined for immediate control of an accident at its source and for initiating appropriate emergency action.

The emergency arrangements should provide for the most effective use of the resources available by providing for allocation of key personnel and facilities for emergency duty and for the effective co-ordination of all the site services. They should also contain provision for assistance from outside the region affected. It is essential that emergency permissible levels should have been established⁽²³⁾.

The IAEA has published an excellent manual on environmental monitoring in emergencies⁽¹⁰⁾ which discusses in some detail rationale, procedures, and potential accidents.

Prompt action following the emergency would be essential to determine the extent of the contamination. In the case of a large release of airborne radioactivity containing gamma-emitting radionuclides, considerable time could be saved in determining the fallout pattern and the areas of

serious contamination by conducting a rapid gamma survey using portable gamma monitors carried in light aircraft, helicopters, or automobiles. Car-borne and aerial survey equipment and techniques have been developed and tested in the United States, Canada, and the United Kingdom (10)(24).

For the past 10 years a sophisticated aerial radiation detection and tracking system has been in operation to assist the U.S. Atomic Energy Commission in monitoring the impact of nuclear facilities on their environment. The system, referred to as ARMS (Aerial Radiological Measuring System), is an integral part of the USAEC environmental surveillance program (25).

The capability for rapid surveys with car-borne instruments has been developed at the Japan Atomic Energy Research Institute's Tokai-Mura facility. Background surveys are performed about twice a year to provide information on levels of natural background radiation at pre-selected points (26).

The emergency environmental sampling program should include the collection of samples of airborne materials, drinking water and critical components in the food chain. Where air-monitoring networks exist around a facility, samples from the network may serve to evaluate radioactive concentrations in the cloud. Where no such networks exist, the collection of air samples may be a futile effort unless the release continues over a relatively long period of time.

Samples of environmental media should be collected throughout the area of contamination to define its boundaries and evaluate the hazard

to the neighboring population. The number and types of samples will depend on the utilization of the affected area (i.e., if food is produced such as milk, vegetables, eggs). The numbers of samples and schedule for resampling will be governed by the duration of the radioactive release and the persistence of significant levels of contamination.

Analyses of samples for gross radioactivity will define the extent of the contaminated area and establish general levels of contamination. Analyses for specific radionuclides are necessary, however, to evaluate the extent of economic damage to property and the hazard to man and to make intelligent decisions with regard to the action required in coping with the emergency.

C. Operational Surveys

Data gathered during environmental surveys performed after a nuclear facility begins operation can be used to evaluate the effluent controls. For larger installations releasing significant quantities of radionuclides to the environs, the data should also be used to estimate the radiation doses received by the population residing nearby. Discharge data should be available to those responsible for environmental surveillance whether they are a part of the operators organization, a separate company, or a state or federal health agency. Availability of such data is necessary if the relationship between radioactive discharges and environmental survey results can be established.

1. Monitoring related to releases to the atmosphere

Figure 6 illustrates some of the environmental media which might be sampled to determine the human exposure resulting from releases of radioactive materials to the atmosphere. Gamma radiation, either

directly from the released cloud or from material deposited on the ground can be measured by integrating type dosimeters continuously exposed at a fixed station and then read periodically. The biggest difficulty is to detect small changes in background exposure rates which normally range from 10 to 20 $\mu\text{R/hr}$.

In the past attempts have been made to use standard personnel dosimetry film for these measurements. However, the film is not sensitive enough to detect the small incremental doses from the plant without exposure periods of a month or more. During this long period high temperatures and excessive moisture often caused erratic, high results.

Energy compensated G.M. Tubes have also been used to measure (and record) ambient gamma exposure rates. Here again the sensitivity limits the detection to changes on the order of natural background levels.

Small ion chambers, such as Victoreen Stray Radiation Chambers, read on a "Pulse Reader" can measure the small doses involved, but care must be taken to minimize leakage through the insulators. Thermoluminescent dosimeters (TLD's) are now being employed at some sites for measurement of environmental gamma doses. A recent development at Hanford has been an appropriate shield and methods for calibration and annealing which allow the use of TLD-200 ($\text{CaF}_2:\text{Dy}$) chips to measure doses as low as a few mR accumulated over a two or three week period.

The most widely used method for monitoring airborne radioactive materials is to draw an air sample through a filter at a fixed flow rate, and then periodically to collect the filter for laboratory analysis. The measurement of alpha activity on the filter is complicated by the fact that the atmosphere normally contains natural alpha activity in concentrations that is usually higher than the permissible concentrations of the long-lived alpha activity one might wish to measure. Fortunately, the natural alpha-emitting radionuclides in the atmosphere are short-lived and if one permits them to decay for 6 or 8 hrs., they will have decayed to a level which makes it possible measure the presence of long-lived emitters⁽¹¹⁾.

A somewhat more reliable procedure is to count the filter at two different standardized times after collection, such as 6 hours, and 48 hours, and then to utilize a nomograph to calculate the quantity of long-lived radionuclides present on the filter.

Concentrations of naturally occurring beta emitters in the atmosphere are about the same order of magnitude of the alpha emitters. However the MPC's of most beta emitters are high enough so that significant increases about background can be detected. Here again, a short decay period after the initial collection will permit the natural radioactivity to decay to negligible levels.

Several types of filter paper are available for air sampling. Plastic membrane filters have a high collection efficiency for submicron

particles and will retain the collected dust near the surface where any alpha emitters present can be detected efficiently.

Airborne radioiodine can be sampled by drawing air through small charcoal cartridges. Both inorganic and organic forms of iodine will be collected efficiently if the temperature and humidity are not excessive, and if the face velocity of the air through the cartridge is kept below 200 feet/minute. Under more severe condition of temperature and humidity charcoal impregnated with KI will exhibit satisfactory collection efficiency.

Air samplers may be equipped with devices for measuring and recording the activity collected on the filter. Stepwise or continuously moving strips of filter paper may also be used if a record of the air concentration vs. time is required. Suitable alarms can be added to indicate high radiation, loss of flow rate, etc.

Tritium oxide can be sampled by drawing in through cylinders containing silica gel. After use the sampler is returned to the lab where the collected moisture is removed by distillation and analyzed for tritium oxide content using a liquid scintillation counter. The sensitivity of the system used at Savannah River Laboratory is 10 pCi/m^3 utilizing 3 ml of distillate, 21 ml of scintillation mixture and a 20 minute counting time⁽²⁸⁾.

Before reuse the silica gel must be thoroughly tried to remove as much of the residual moisture (and tritium oxide) as possible, to limit cross contamination of samples.

Surface deposition can be monitored by repetitive instrument surveys or soil sampling at fixed locations around a facility. A more sensitive and reliable method is to periodically analyze deposition collection devices placed in the field. These can be glass--wool paper, paper coated with a sticky surface, trays of water, or elaborate pots containing strips of paper to stimulate grass.

Analysis of the collectors is often done by ashing at high temperature although volatile nuclides such as iodine and ruthenium will be lost in the process. Flat collectors can be covered with a thin layer of plastic and counted directly on a large area proportional counter.

Grass is an excellent medium for trapping surface fallout and can be used as a sensitive indicator of deposition. It is particularly useful if a deposit of fresh fission products is suspected (11).

Foodcrops such as vegetables, cereal grain and milk can also contain radioactivity originating from atmospheric releases. In the vicinity of larger facilities where significant quantities of fission products, such as iodine, cesium and/or strontium, are released, milk should be sampled approximately every two weeks for analysis by gamma spectroscopy especially for radioiodine. Composite milk samples can be analyzed for longer-lived nuclides on a quarterly basis. Other foods should be sampled at harvest time and analyzed by gamma spectroscopy and for ^{89}Sr and ^{90}Sr .

Bovine thyroids are a more sensitive indicator of the presence of radioiodine in the environs than are milk or vegetation (27).

Arrangements can be made with a veterinarian to collect thyroid samples at a local slaughter house for shipment to the laboratory for analysis.

2. Monitoring related to releases to surface waters

The release of radionuclides to streams, lakes, or oceans from a nuclear facility can lead to radiation exposure through a variety of pathways. Figure 7 indicates the kinds of environmental measurements required to define the radiation doses to people in the environs. Drinking water, fish, waterfowl, and foods irrigated with contaminated water are the routes of internal exposure;

fishing and hunting on the shoreline, boating, and swimming, and handling of contaminated fishing gear, are possible routes of external exposure.

Samples of receiving waters are logically taken near the point of public use, i.e., where the recreation takes place, or where the water is withdrawn for drinking or for irrigation. If the effluent is so diluted by this time that accurate measurement of the concentration is not possible, then sampling nearer the discharge point would provide better radiological control. Samples of a flowing stream taken upstream of the facility and far enough downstream for thorough mixing to have taken place, can be compared to estimate the radioactivity added to the stream.

Normally radionuclides of very short half-lives will not be of great concern and weekly samples of water should be sufficient. Determination of long-lived radionuclides can be made in samples continuously composited over periods of a week or a month. This is especially advantageous if the release rate is not uniform or if the river flow rate is variable. Measurements of gross beta activity may be sufficient when the concentrations are low (≤ 10 pCi/l) although the presence of natural uranium in some streams may dictate isotopic analyses at these levels.

Samples should be as representative of water actually consumed as possible. Municipal water plants which employ flocculation and filtration steps will remove a significant fraction of certain radionuclides. For example, experience with the water plants at

Richland and Pasco, Washington, downstream of the Hanford project indicated the following removal efficiencies: 90% for ^{51}Cr , 80% for ^{131}I , 40% for ^{65}Zn , 30% for ^{64}Cu , and 20% for rare earths.

Direct measurement of radiation exposure over shoreline mud can be made with suitable portable instruments employing scintillation detectors or large volume ion chambers. Shoreline exposures and immersion dose rates in the water can be measured with dosimeters such as small ion chambers or TLD's left in position for one to four weeks.

Samples of sediment upstream and downstream from the discharge point can be collected before and after the plant starts operating for laboratory analysis. Careful selection of sampling rates and proper interpretation of results is important.

The quantity of radionuclides present at a given time in a given shoreline location will be affected not only by the release rate, but also by the recent changes in stream velocity and elevation and season of the year (which will affect the types and amounts of organic debris available for deposition).

Fish and waterfowl can concentrate radionuclides through aquatic food chains. Even upland game birds and poultry living near the water can acquire radionuclides through ingesting contaminated aquatic insects and water.

Samples of fish and game birds should be harvested in season and at locations accessible to sportsmen. Poultry and eggs should be sampled periodically throughout the year.

Where effluents are discharged directly to the ocean or reach the ocean via the receiving stream, samples of seafood including shellfish should be collected. Monthly sampling of all of the above food is normally sufficient, since the concentration of radionuclides will change only slowly with time⁽⁹⁾.

Pastures irrigated with contaminated water should be sampled about two to four times per year at times the milk from the cows fed on it is sampled. Gamma spectrometric analyses and radiochemical analyses for ^{89}Sr and ^{90}Sr should be performed on each sample.

Food crops should be sampled at harvest and analyzed for gross beta activity unless significant concentrations of radionuclides are present. In that case, gamma spectroscopy and analysis for ^{89}Sr and ^{90}Sr is required.

3. Monitoring in relation to release to ground

Liquid wastes may be released directly to the ground or may seep into the ground from disposal ponds or trenches. Proper selection and management of the disposal site will eliminate most of the environmental problems. Radionuclides leaching from the disposal site into surface waters can be monitored by collecting samples of the surface waters. Where necessary ground water can be monitored through wells sunk around the periphery of the site. Nuclides which generally move more freely with underground water flow include tritium oxide, ^{106}Ru and in certain chemical complexes ^{60}Co . Many soils have a capacity for retention of strontium and

cesium (dependent to some extent on the pH and chemical composition of the waste solution) and these nuclides will not normally migrate a significant distance through the soils underlying the disposal site. However, tests of the behavior of radionuclides from samples of the actual effluent in the particular soil involved should be made prior to establishment of any disposal site discharging large quantities of radionuclides to the ground.

VII. Typical Surveillance Programs

A. Environmental Monitoring Around Facilities Handling Uranium

Tsivoglou⁽²⁹⁾ described the environmental monitoring program around a uranium mill in Colorado. Little airborne wastes are generated at this uranium mill. Waste gases from furnaces and other equipment are generally scrubbed to remove particulates before release to the atmosphere. Samples of river water and sediment are collected from the river where the liquid wastes are discharged. Water samples upstream and downstream of the mill are taken by means of a pump and timer set to deliver a small volume of water every 15 minutes to a large collection bottle. Samples are removed weekly and either analyzed weekly or composited for monthly analysis. Analysis is principally for radium-226 and uranium although analyses for ^{210}Pb , Th and Po have been made on a few samples. Sediment samples are analyzed for ^{226}Ra and gross alpha activity. Radium-226 has been determined by the radon emanation technique, uranium by fluorometric procedure and gross alpha activity with an internal proportional counter.

Small quantities of uranium are released to the atmosphere from several stacks of the Springfield Works, near Preston, Lancs., U.K. (30). Traces of the released uranium may deposit on vegetation grazed by cattle. Uranium ingested by cows is not transferred to their milk and hence the main criteria is protection of the health of the animals rather than human radiation exposure. Samples of bovine feces were collected twice during 1969 from four farms close to Springfield site and from a central farm several miles away. In all but one case samples contained 5 μg of uranium per gram of dried sample or less. The one exceptional sample contained 30 μg U/g sample. The limit derived on the basis of the chemical toxicity of uranium is 220 μg U/g.

B. Nuclear Power Reactors

The Bureau of Radiological Health of the U.S. Public Health Service (now part of EPA) have published several reports discussing monitoring programs in place around existing power reactors (31-33). Table IV below is extracted from one of their reports (13) and summarizes a typical environmental surveillance program for power reactors.

A program similar to that described in Table IV was recommended by the World Health Organization for surveillance around nuclear reactors and fuel processing plants (8). The main difference was the additional recommendation of ^3H , U and Pu analysis in samples of water and sediments.

Description of the existing or planned environmental monitoring programs at nuclear power sites are available through public documents filed with the Atomic Energy Commission or in some instances through open literature reports (34-36).

Table IV

Typical Environmental Surveillance Program for a Nuclear Power Plant⁽¹³⁾

Recommended Surveillance Program

<u>Vectors or Indices</u>	<u>Relative Frequency</u>	<u>Analyses</u>	<u>Sampling Locations</u>
Surface Water Receiving waters of the facility	Continuous composite or weekly grab	Gross beta and gamma scans. Periodic analysis for 3H 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 re- ceiving waters as a raw water source.
Bottom sediments	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 annually)	Gross beta and gamma scans	Supplies within 5 miles of the facility
Air:			
a) Inhalation	High-volume samples oc- casionally Low-volume samples daily or weekly	Gross beta and gamma scans of filters & cartridges	Populated areas within 5-15 miles of the facility
b) Immersion	Dosimeters changed monthly	Integrated dose due to noble gases by appro- priate reader device	
Milk	Monthly Quarterly	Gamma spectrum analysis for ¹³¹ I ⁸⁹ Sr and ⁹⁰ Sr or total Sr by beta analysis	Dairy herds within 10-15 miles of the facility Dairy herds within 10-15 miles of the facility

Table IV (cont'd)

<u>Vectors or Indices</u>	<u>Relative Frequency</u>	<u>Analyses</u>	<u>Sampling Locations</u>
Aquatic biota	Variable	Gamma spectrum analysis for selected radio-nuclides	Near the reactor's outfall or above and below if receiving water is a stream
Food crops and other vegetation	Seasonal (before or at harvesting time)	Gamma spectrum analysis	Within a 10-15 mile radius of the facility
Soil	Annually	^{90}Sr and ^{137}Cs or gross beta	Prevailing downwind direction in nearest agricultural areas

C. Nuclear Fuels Reprocessing Plants

1) NFS Plant, New York

The Nuclear Fuels Services plant in West Valley, New York, is the first private facility for reprocessing power reactor fuels in the U.S. Two complimentary environmental surveillance programs are in operation around the site--one is maintained by the operator of the plant and one by the New York State Health Department. The plant is designed to process one ton per day of reactor fuel of 20,000 MWD/ton exposure. The plant operating license limits the discharge of ^{131}I to 3 Ci/yr and noble gases, essentially all ^{85}Kr , to 10^4 Ci/day.

About 40,000 gallons per day of liquid effluent are released through a series of ponds and lagoons and eventually into a nearby creek.

Sampling and analysis is performed daily for gross alpha and beta activities, and weekly for isotopic analysis. Low concentrations of ^{58}Co , ^{60}Co , ^{90}Sr , ^{95}Zr , ^{95}Nb , ^{103}Ru , ^{106}Ru and ^{137}Cs are present in the effluent. If necessary, the effluent can be temporarily detained in the ponds or diverted to storage and/or treatment facilities.

Both the plant operator and NYS Health Department collect samples of air, water and milk in the vicinity of the site. During the pre-operational period the NY State Health Department collected and published detailed data pertaining to population, surface water supplies, agriculture, stream biota, and livestock within a 25 mile radius of the plant site.⁽³⁷⁾ Background radiation levels were also measured in a pressurized ion chamber at about 30 sites during the pre-operational environmental program⁽³⁸⁾. Two soil samples were collected and analyzed for gross gamma activity at each of four locations

on the plant site at a 12 month interval.

Milk samples were collected from six farms and analyzed for gross gamma activity and for several fission products. Low concentrations of the fallout nuclides ^{89}Sr , ^{90}Sr and ^{137}Cs were detected in nearly all milk samples. Surface water samples were collected from numerous streams near the plant site and analyzed for gross gamma, fallout nuclides, uranium and radium. Only rarely were positive measurements obtained. Sampling sites were also established for drinking water, bottom mud, fish and air samples.

After operation of the plant for a few years, the Northeastern Radiological Health Laboratory of the USPHS (now part of EPA) performed a special survey of the NFS plant environs⁽³⁹⁾. Samples of milk, drinking water, fish, and deer were collected and analyzed for H-3, Co-60, Sr-90, Ru-106, Cs-134, and Cs-137. Measurements of Kr-85 in air were also made. The study concluded that "the presence of Nuclear Fuels Services. . . . did not significantly increase the radiation dose to the 'typical individual' in 1968 above that due to fallout and natural radiation".

2. Windscale Works, United Kingdom

The Windscale Works in Cumberland, UK, provides a good example of the complex monitoring program that could be required of a fuels reprocessing plant⁽²¹⁾⁽³⁰⁾⁽⁴⁰⁾.

The following description of the Windscale environmental surveillance program is essentially that given by Dunster, et.al. in reference⁽²⁹⁾.

The important details of these pathways are summarized in Table V.

Three important pathways were identified and used as the basis for monitoring at the outset of the Windscale program. The most important pathway turned out to be the consumption of "laverbread," which is manufactured in South Wales from a species of edible seaweed, Porphyra umbilicalis. This weed is harvested from the seashore in the vicinity of the discharge area, and monitoring consists in monthly sampling at 11 sampling stations and in measurement of the critical nuclide, ^{106}Ru . The data obtained, plus knowledge of harvesting, manufacturing, and consumption rates, are sufficient to assess the radiation exposure of laverbread consumers. Other nuclides, notably ^{95}Zr — ^{95}Nb , ^{103}Ru and ^{144}Ce , are of minor radiological importance; occasional checks, guided by effluent data, are sufficient to confirm that they remain unimportant.

A second smaller population group is subject to a small fraction of the acceptable radiation exposure from external radiation. This group is made up of fishermen working in an estuary some 6 miles from the discharge area, where trapped silt is contaminated with gamma-emitting radionuclides. The critical nuclides are ^{95}Zr — ^{95}Nb and ^{106}Ru , ^{103}Ru , ^{137}Cs and ^{144}Ce are also found, but they are normally of minor importance. Monitoring for individual radionuclides is not necessary for environmental control, which can be assured by monthly measurements of the gamma-radiation dose rate at selected working positions in the estuary.

A third potential group considered in the early years, sea fishermen, receives only minor exposure, and therefore monitoring needs to be carried out relatively infrequently. These fishermen eat fish caught in the pipeline area to a larger extent than any other member of the

Table V

(21)

Exposure Pathways of Windscale Irish Sea Radioactive Waste Discharges

Pathway	Exposed Population Group	Daily Consumption Rate or Annual Hours of Exposure	Exposed Organ	Radionuclides Contributing to Exposure	Derived Working Level*	ICRP Recommended Dose Limit Rems/Year	Typical Exposure of the Population Group Concerned Rem/Year
Porphyra (seaweed)	Laverbread consumers in South Wales, 2.6×10^4 persons (critical group 100)	160 g laverbread (~80 g seaweed)	G.I. tract (L.L.I.)	^{106}Ru (critical) ^{144}Ce	300 pc/g (^{106}Ru + ^{144}Ce) in the seaweed	1.5	0.6 to critical group
Estuarine silt	Fishermen, 10 persons	350 hr	Total body	^{95}Zr , ^{95}Nb , ^{106}Ru	1.4 mrems/hr.	0.5	0.05
Fish	Local fishermen, 100 persons	25 g	G.I. tract Total	^{106}Ru ^{137}Cs	900 pc/g 1800 pc/g	1.5 0.5	0.002 0.0005
Fishing gear	Fishermen, 100 persons	500 hr	Hands	^{106}Ru , ^{144}Ce	15 mrems/hr	7.5	0.02

* The Derived Working Level is that concentration or dose rate which would expose members of the public to radiation doses equal to the dose limits recommended by the ICRP

public. Plaice from these fishing positions are sampled quarterly, and only traces of ^{137}Cs and ^{106}Ru are found. These fishermen are also open to external exposure (from beta particles primarily) from handling contaminated fishing gear, but in practice such exposure has been found to be quite insignificant.

In practice, some monitoring of all three pathways is carried out, but adequate control of the Windscale sea discharge could be provided by the seaweed program in conjunction with effluent analyses. The relations between levels in this critical material and the other environmental materials are sufficiently well understood that, provided certain limits to effluent compositions are observed, the seaweed program will ensure more than adequate control of all other routes.

Other types of environmental surveillance related to discharge to the atmosphere are also carried out⁽³⁰⁾. During 1969 milk samples were collected from 5 farms within two miles and 5 farms between two and four miles from the site. Samples were taken daily for Sr-90 and Cs-137 and every two weeks for I-131. Samples of milk were also collected from two more remote farms and a Milk Marketing Board for control purposes. The concentration of I-131 found in 1969 in all inner and outer zone milk samples was less than 20 pCi/l.

Concentrations of Sr-90 and Cs-137 in the outer zone milk samples were not significantly higher than those found in the "control" samples. Concentration of these two nuclides in milk sampled in the inner zone were about twice as high as those found in the outer zone reflecting

both recent and past atmospheric releases from the plant. The levels measured (39 pCi $^{90}\text{Sr/g Ca}$ and 170 pCi $^{137}\text{Cs/liter}$) were only a small fraction of the Derived Working Levels (DWL) for milk. (The DWL is defined as that concentration which if maintained continuously would lead to radiation exposures of people at the limits recommended by the ICRP.)

D. Environmental Monitoring Program at the Tokai-Mura Research Institute

The environmental monitoring program at the Tokai Research Establishment of the Japan Atomic Energy Research Institute (JAERI) and the results for the calendar year 1969 were summarized in JAERI-memo-4175⁽²⁶⁾.

The monitoring program includes measurements of environmental media and of effluents released from research reactors, "hot" laboratories, a radioisotope production facility and a Van de Graaff accelerator.

Atmospheric releases from three reactors totaled 20,000 Ci ^{41}Ar and 0.1 Ci ^{38}Cl during 1969. About 1.2 Ci of water vapor was released from the accelerator, and about 0.1 Ci ^{131}I from a hot laboratory, a radioisotope facility and a reprocessing test facility.

Radioactive liquid wastes from the facilities were discharged to the sea through three drains. Those with concentrations of less than $10^{-5} \mu\text{Ci/cc}$ are immediately discharged and the others are treated at the waste disposal plant before discharge. Total activity discharged in 1969 was ~ 0.1 Ci, 90% of which was ^3H produced in the JJR-2 research reactor.

Gamma exposure rates are continuously measured at 4 monitoring "stations" and 16 monitoring "posts" and also periodically at 20 fixed points. Numerous film badges are distributed on the site boundary to measure exposure in the event of an accidental release of radioactivity. The

capability for rapid surveys with car-borne instruments has been developed, and surveys are performed with the equipment once or twice a year to establish the background radiation over the pre-determined routes.

The four monitoring stations are equipped with continuous air samplers and the radioactivity collected on the filters is automatically counted every ten minutes. The filters are brought to the laboratory monthly for analysis of gross beta and radionuclides.

Soil samples are collected twice a year at the fixed monitoring points for analysis of gross beta and radionuclides. Agricultural products including milk, are also sampled twice a year but are analyzed by ashing and counting the residue. Sources of drinking water are sampled twice a year for total beta analysis. Drain water is collected twice a year for total beta and Cs-137 analysis.

Rain water is collected daily and deposition monthly (on gummed paper and in water filled basins). Both are analyzed for total beta and radionuclides.

Meteorological measurements are continuously recorded using a 40-meter tower located at the institute. Oceanographic observations are taken in areas off of Tokai ten times a year. Marine biological materials are sampled at the same time. Marine products are purchased once a year at ports after they are landed and analyzed for total beta activity.

Results of this monitoring program indicated that essentially all of the environmental radioactivity measured in soil and sediment, and water was due to either material background or fallout materials.

The exposure from ^{41}Ar released from the JRR-2 reactor could be measured within 1000 meters of the institute. Concentrations of gross radioactivity in various foods were 1 pCi/ml of fresh milk, 2 to 6 pCi/g in grain and vegetables and 6 pCi/g in bonita muscle.

E. Environmental Surveillance at the Hanford Project

The U.S. AEC Hanford project is a complex of production reactors, fuels fabrication facilities, fuels reprocessing plants, and research facilities. The eight older plutonium producing reactors, now shutdown, utilized a once thorough cooling system. Columbia River was passed through the reactors, then into delay ponds and finally back into the river. The effluent contained fission products and neutron activation products.

Atmospheric releases from the fuel reprocessing plants included I-131 and some particulate material principally Ru-106. Liquid effluents from the separations plants ^{are} not released directly to portions of the environment accessible to the public. High-level wastes are stored in tanks. Medium level wastes are released to the ground where all the radionuclides except ^3H and ^{106}Ru are effectively retained by the soil which is up to 400 feet thick above the groundwater. Low concentrations of these two nuclides can be measured in groundwater which migrates very slowly towards the Columbia River. The environmental surveillance program at Hanford reflects the past need to monitor potential pathways of exposure from both the reactor effluents discharged to the river and the reprocessing plants' effluents released to air and ground. Table VI below summarizes the types and frequency of sampling and analysis performed during 1969 and 1970.

The results of this environmental surveillance program have been evaluated in terms of radiation doses received by a hypothetical "maximum

individual" and an average Richland resident and reported annually. The dose estimates reported for 1969⁽⁴¹⁾ are illustrated in Figures 8 and 9.

Table VI

Environmental Monitoring Program at Hanford

<u>Item</u>	<u>Frequency</u>	<u>Analysis</u>
<u>Effluents</u>		
Gaseous	Continuous Weekly	Particulate & Halogens Isotopic
Liquids-- Released to River Released to Ground	Continuous Batchwise or daily	Gross Activity Isotopic
<u>Environmental Media</u>		
Air	Weekly/Bi-weekly Monthly Composite Quarterly Composite (Total 42 locations)	Gross Beta, Alpha, I-131 Gamma Scan Sr-90, Pu-239
Surface Water	Weekly to Quarterly (3 locations up and down- stream of Project)	Isotopic - Frequency varies with nuclide
Sanitary Water	Weekly/Monthly (3 locations)	Isotopic - Frequency varies with nuclide
Ground Water	Monthly to Semi-annually (~180 wells)	Gross Beta, ³ H, Nitrate ion - Frequency varies with location
Milk	Weekly/Monthly Quarterly (4 farms, 3 commercial sources)	I-131, Gamma Scan Sr-90
Fish	Semi-monthly Monthly Composite	P-32 Gamma Scan
Gamebirds	Seasonally	P-32, Gamma Scan
Other Foodstuffs	Monthly/Quarterly/Seasonally (Farms and local stores)	P-32, Gamma Scan, Sr-90, Frequency and specific analyses vary with both food and location.
Shellfish	Monthly (one location)	P-32, Gamma Scan

Table VI (cont'd)

<u>Item</u>	<u>Frequency</u>	<u>Analysis</u>
External Dose	Semi-weekly (two locations)	Ion Chambers
	Monthly (58 locations)	TLD
Ground Deposition	Monthly (49 control points)	Portable Survey Meters
	Monthly (plant roots)	Car-borne Scintil- lation Counter
	Semi-annually (fixed flight patterns out to 200 miles from project)	Aerial Survey Scintillation Counter

VIII. Manpower and Laboratory Requirements

The operation of a surveillance program embraces a number of activities from designing the survey, directing the survey, collecting samples, and analysing samples, to interpreting the data obtained. Professional advise from many sources may be required during the planning phase and at least one professionally trained scientist is needed to supervise the program initially. The scientist in charge of the survey should have an understanding of, and access to advisers in, sampling techniques, operation and maintenance of counting equipment, chemical analyses, statistical evaluation of data, and general health physics.

The number of supporting technical staff needed will depend a great deal upon the magnitude and scope of the survey. It is generally found that someone with the equivalent of a high school education can carry out the routine procedures used in environmental survey work. Training is essential, however, if samples from the field are to be properly collected and analysed according to specialized procedures⁽⁸⁾⁽⁹⁾.

The equipment and laboratory facilities required vary according to the scope of the survey. The measurement of gross activity requires the usual facilities of a small chemical laboratory supplemented by relatively simple counting devices. Analysis for specific nuclides will normally not require other than conventional laboratory equipment, but it is expensive in time. Further, the sensitivity of the counting equipment generally needs to be of greater than if, for example, only gross beta activity is measured. Time may be saved by making use, when this is possible, of gamma-ray spectrometry, but a spectrometer of varying degrees of complexity is required⁽⁸⁾⁽⁹⁾.

IX. Summary

The scope of environmental surveillance at a particular facility will depend upon the type and extent of nuclear operations carried on within it. Where preliminary surveillance indicates that the public exposure resulting from the discharge of wastes to air and water will be only a small fraction of the dose limits, environmental surveillance might be drastically reduced. The objectives of radiological control can then be met by occasional checks on the discharge rates or on environmental media where cumulative effects or reconcentration of the effluent radionuclides is suspected.

For radionuclides of long half-life infrequent sampling (quarterly or annually) is normally sufficient unless there are rapid fluctuations in the discharge rates or a major change in the environmental conditions. Nuclides with relatively short half-lives can be sampled at intervals of two to three half-lives⁽⁸⁾. Of course, supplemental samples should be taken if results show any significant or unexpected increase.

Advantage should be taken of data gathered by nation-wide surveillance networks established for measuring world-wide fallout. In addition, data resulting from effluent monitoring at the facility should be utilized in the planning of new or revised surveillance programs. The primary aim being to keep the number of samples and analyses to the minimum necessary to ensure adequate control.

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EXPOSURE LIMITS FOR THE PUBLIC

INDIVIDUALS

MREM PER YEAR

POPULATIONS

500 - WHOLE BODY 170

1500 - THYROID 500

1500 - G.I. TRACT 500

1500 - BONE 500

Figure 1

DOSE CALCULATIONS PEOPLE LIVING IN AN ENVIRONMENT CONTAINING TRACE AMOUNTS OF RADIOACTIVITY

Figure 2

Figure 3

THE ^{65}Zn EXPOSURE PATHWAY AT BRADWELL POWER STATION, U.K.

Figure 4

THE ^{32}P EXPOSURE PATHWAY AT HANFORD WASHINGTON

Figure 5

EXPOSURE PATHWAYS FROM THE ATMOSPHERE

Figure 6

EXPOSURE PATHWAYS FROM REACTOR EFFLUENT

Figure 7

ESTIMATED DOSES TO THE MAXIMUM INDIVIDUAL - 1969

Figure 8

ESTIMATED DOSES TO THE AVERAGE RICHLAND RESIDENT -1969

Figure 9