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FOREWORD

Many establishments handling radioactive materials produce and to some extent also discharge radioactive waste as a part of normal operation. The radiation doses to which members of the public may be directly or indirectly exposed during such operation must remain below the stipulated level; as the Agency Basic Safety Standards and many relevant national regulations state, measurements should be undertaken to ensure this basic requirement.

The purpose of this manual, which has been prepared with the help of two consultants, Dr. R. Garner of the United Kingdom and Dr. D. Mechali of France, is to provide technical guidance for setting up programmes of routine environmental monitoring in the vicinity of nuclear establishments. Monitoring in the event of an accident is the subject of a separate Agency Manual entitled Environmental Monitoring in Emergency Situations.

The Annex gives a number of examples of routine environmental monitoring programmes currently in use in different countries. It must be emphasized that some of these programmes have broader objectives, such as research, than is required by the routine safety controls recommended by the manual.
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ANNEX II: ENVIRONMENTAL MONITORING AROUND THE NUCLEAR RESEARCH CENTRE AT LA CASACCIA, ITALY .................................................... 30
S. Tagliati and O. Ilari

ANNEX III: ENVIRONMENTAL MONITORING AROUND THE NUCLEAR POWER STATION AT CHAPELCROSS, ANNAN, SCOTLAND ................................................. 45
J. H. Martin

ANNEX IV: ENVIRONMENTAL MONITORING AROUND A LONG-TERM STORAGE PLACE FOR SOLID RADIOACTIVE WASTES IN CZECHOSLOVAKIA . 55
J. Kortus

ANNEX V: ENVIRONMENTAL MONITORING AROUND A URANIUM MILL IN THE UNITED STATES OF AMERICA ......................................................... 63
E. C. Tsivoglou
1. INTRODUCTION

The purpose of this manual is to provide guidance for setting up programmes of environmental monitoring in the vicinity of establishments which in normal operation discharge radioactive materials to the environment. It is not intended that it should bear any regulatory nature.

In the context of this manual environmental monitoring refers to the measurement of external radiation levels and levels of contamination in air, water and foodstuffs etc. to which members of the public may be exposed directly or indirectly as a result of the normal operation of an establishment. Monitoring in the event of an accident is the subject of the Agency Manual on Environmental Monitoring in Emergency Situations.

In the main text of the manual, consideration is given to basic principles underlying the development of an environmental monitoring programme. Application of these basic principles to a specific situation will depend upon the operations of the establishment, the nature of any statutory control measures required by national or local authorities and, most important, upon the environmental conditions. The aim is to show how a survey, adequate for purposes of radiological control, can be carried out with limited resources of trained manpower and equipment.

The Annexes give a number of examples of the routine environmental monitoring programmes currently in use in specific establishments in different countries. It must be emphasized that the organization and the results described are intended as examples only, and that the objectives of some of these programmes are more broadly defined than the objectives of the type of programme described in this manual.

The manual should be read in conjunction with the following Agency Safety Standards:

- Basic Safety Standards (Safety Series No. 9)
- Safe Handling of Radioisotopes (Safety Series No. 1)
- Code of Practice for Provision of Radiological Protection Services (in preparation)

Detailed information on disposal of radioactive wastes in the environment is given in the Agency reports:

- Radioactive Waste Disposal into the Sea (Safety Series No. 5)
- Radioactive Waste Disposal into the Fresh Water (Safety Series No. 10)
Radioactive Waste Disposal into the Ground (in preparation)
Techniques for Controlling Air Pollution from the Operation of Nuclear Facilities
Details of sampling methods, analytical techniques and equipment are available in the following publications:
Methods of Surveying and Monitoring Marine Radioactivity (in preparation)
Organization of Survey for Radionuclides in Food and Agriculture (FAO Atomic Energy Series No. 4)

2. THE OBJECTIVES OF ENVIRONMENTAL MONITORING

The normal operation of many establishments dealing with radioactive materials inevitably involves the production of radioactive waste products. Complete removal of radioactivity from effluents discharged to the environment is practically impossible to achieve so that these effluents will always contain some amounts, however small, of radioactive waste material.

The design of a nuclear establishment must ensure that, under normal operating conditions, any wastes discharged from it will not give rise to radiation exposures of members of the public in excess of those stipulated by competent authorities. Recommendations on permissible radiation exposures are contained in the IAEA publication, Basic Safety Standards, and their use in relation to waste discharges is discussed in Radioactive Waste Disposal into the Sea, Radioactive Waste Disposal into the Fresh Water, and Radioactive Waste Disposal into the Ground.

Regulations governing the discharge of radioactive waste usually require that measurements be made during the course of the normal operation of an establishment in order to demonstrate that radiation doses remain below the stipulated levels. These measurements may take the form of an environmental monitoring programme. Thus, the primary objective of such a programme is radiological control.

Other reasons than radiological control may be adduced for carrying out routine environmental surveys. These can be broadly classed as (i) scientific investigation and (ii) public relations.
A survey carried out as part of an investigation programme designed to provide data for better understanding of the potential hazards arising from normal operation of a plant will inevitably be very similar to one designed for radiological control, but may have to be more extensive and more elaborate. In practice such a survey may be applied in order to predict future trends.

Circumstances may demand that surveys be carried out so as to provide tangible evidence that the public is being protected even if they are not needed for other purposes. Such surveys should still be designed to provide data capable of interpretation in terms of radiation doses, and the factors influencing their design are thus similar to those for other types of survey.

A pre-emergency survey, designed to provide background information so that the effects of an accidental release may be interpreted more accurately, may be sometimes usefully interlinked with the routine environmental survey. However, its objectives should be clearly distinguished from those of the routine survey, and the latter should not be regarded as a method of exercising emergency measures.

Measurements in the environment may not always be necessary. If discharges to the environment are trivial, or when experience indicates that sufficient data have been accumulated, control of waste discharges can sometimes be exercised solely by monitoring the wastes before or during discharge.

3. PLANNING OF ENVIRONMENTAL MONITORING

3.1. Principles underlying the planning of an environmental monitoring programme

The form of an environmental monitoring programme is determined by a number of factors, not the least being the objective of the survey. It is assumed that the primary objective is to control the radiation doses received by members of the general public as a result of the normal operation of an establishment. The IAEA Basic Safety Standards, based on the recommendations of the International Commission on Radiological Protection, provide recommendations that include maximum permissible doses for groups of the general population, and maximum permissible concentrations of radioactive
materials in air and water, derived from maximum permissible body burdens and maximum permissible continuous intakes by inhalation and ingestion.

If the objective of a monitoring programme is to ensure that acceptable doses are not exceeded, measurements intended to achieve this objective must be capable of yielding information 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.

To identify the major sources of exposure and hence the materials which can be most usefully sampled, a comprehensive review is needed on such items as:

(i) The type and amount of radioactive materials likely to be discharged as the result of normal operations, and the physical and chemical form in which they exist;
(ii) The method of discharge;
(iii) The physical properties of the environment which govern the dispersion of activity, e.g. local topography, meteorology and hydrology;
(iv) The way in which the environment is used by man, e.g. water supplies agricultural practices, fishing activities etc., and the distribution of agricultural products, fish etc.;
(v) The characteristics of the exposed population, its distribution, social and recreational activities, means of earning its livelihood, dietary habits and the origin of the food it consumes.

It is apparent that such a review is a complex operation, involving many scientific disciplines, and it should be carried out in consultation with appropriate specialists having a knowledge of local conditions.

The review will permit the identification of
(i) The principle routes of exposure;
(ii) The population which, because of its social or dietary habits, is at greatest risk from any of these routes;
(iii) The potentially most hazardous nuclides discharged.

The review, if conducted adequately, will allow a preliminary quantitative assessment of the radiation doses likely to be received by members of the public as a result of the discharges contemplated.
It may well be that these doses are so small relative to those stipulated that it is judged that no environmental monitoring programme is needed for radiological control. Other reasons, such as maintenance of adequate public relations, may then have to be considered before a final decision is made.

If it is decided that environmental monitoring is necessary, the review will establish the materials to be examined, and the sampling points and the frequency of sampling to be determined. These aspects are considered in detail in section 4.

The monitoring programme should be examined at intervals to ensure that it has been properly formulated and that it achieves its objectives. Changes in the operations of the establishment; in the characteristics of its environs, or in the practices of potentially exposed populations may require a modification of the programme.

Experience has shown that such reassessment may lead to reductions in the scale of routine environmental monitoring without loss of scientific information. In cases where wastes are also monitored before discharge, sufficient data may have accumulated to allow empirical relationships between the levels of activity measured in the environment and the rate of discharge to the environment to be established. The control of radiation doses to members of the public is to be exercised solely by measurements made at the point of discharge.

3.2. Pre-operational and background surveys

The operator of a nuclear establishment is held responsible only for that amount of radioactive material which the operation of 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 information both on the pre-existing level of radioactivity in the environment and on subsequent additions from sources other than his own establishment.

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.

All living organisms are exposed to radiation - from cosmic-ray bombardment from space, and from radioactive materials, such as uranium, radium, thorium and their daughter products, and potassium-40, which occur naturally in the environment. Character-
istically, the levels of natural radioactivity vary widely from place to place and also from time to time. An environmental monitoring survey must obviously take due regard of the presence of natural radioactive materials. For example, the presence of natural potassium-40 in biological organisms can otherwise be misleading.

A nuclear explosion is accompanied by the production of varying amounts of fission products, depending on the extent to which the explosion involves fission processes, and of induced radioactivity in the materials of the weapon or in the environment. The products of the explosion are deposited on the earth's surface as fall-out over a period of from a few minutes to many hours in the case of local fall-out; a few months in the case of tropospheric fall-out; or several months or years in the case of material injected into the stratosphere. Since the half-lives of the radioactive products of nuclear fission vary from less than a second to many years, the composition of the fission-product mixture changes greatly with time. For a short time after detonation nuclides with short half-lives predominate: after several years only nuclides with long half-lives, such as $^{90}\text{Sr}$ and $^{137}\text{Cs}$, remain. Not only does the chemical composition of a fission product mixture, and hence of fall-out, change markedly with time, but also the physical properties. Indeed, many factors may so affect the relative proportions of fission products in fall-out that prediction of future levels of individual nuclides in any medium is rendered difficult.

Pre-operational measurements of radioactivity in the environment may in some cases provide bases for evaluating the radioactivity originating from the establishment, but will not usually provide the best way of distinguishing between activity from the establishment and that from other sources. They 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. To do this, methods used in a pre-operational survey for radioactivity should be identical with those to be used in the routine surveys.

The natural activity of most environmental samples will vary seasonally and, to a lesser extent, from year to year. Pre-operational results can thus only approximately be extrapolated to later years. In most cases, radioactivity resulting from the operation of an establishment can be distinguished from natural activity by
appropriate chemical and physical identification of the radionuclides. Therefore, it is better, wherever possible, to use specific analytical techniques in order to assess the contribution from the establishment.

More difficulty sometimes exists in distinguishing the establishment's contribution to environmental contamination from that due to fall-out. The best that can be done is to interpret the routine environmental survey data against any results that may be available from more extensive fall-out programmes. It is obviously important that comparable methods should be used in both the local and more extensive surveys. Because of the considerable variation in deposition of fall-out that can occur between situations only a short distance apart, assessment of the relative contributions can be only approximate.

The major radioactive component of wastes discharged from most nuclear establishments is fission products. Therefore, difficulty may be met in distinguishing extraneous contamination arising from the operation of some other nuclear plant in the vicinity. Circumstances may sometimes permit the resolution of the various contributions by the use of specific analytical techniques.

When releases to the environment from a number of establishments are individually small but cumulatively produce significant environmental contamination, a carefully designed but usually very limited programme may be required. It may well be decided that this should be the responsibility, not of any individual establishment, but of public health authorities.

3.3. Selection of analytical methods

Because of its simplicity and low cost, measurement of gross activity is frequently chosen for environmental monitoring but, except under special circumstances, analysis for gross activity is unsatisfactory. The basic objective of a monitoring programme should be the evaluation of radiation dose, and the measurement of gross activity does not usually permit such an evaluation. Further, if the permissible levels of potentially dangerous radionuclides are low in comparison with the levels of less hazardous isotopes, or of naturally occurring nuclides such as potassium-40, the measurement of gross activity is incapable of detecting a significant increase. Again, if the composition of the contaminating material is unknown, it is usually necessary to assume that the whole of the activity measured is due to the most hazardous nuclide; hence the method can be un-
duly restrictive. If, on the other hand, only one nuclide is present, or if the composition of a mixture is known, measurement of gross activity may be adequate for preliminary analysis.

For these reasons and those set out in section 3.2, it follows that analytical methods should generally aim at the identification of individual nuclides. Unfortunately, refined methods of analysis are more costly than measurements of gross activity and require more highly trained personnel. But, they allow a more complete appraisal of the situation with fewer samples. The final choice of method must depend upon local circumstances.

Often the objective of the survey will be achieved if it can be demonstrated that specified levels of radiation or of radioactivity in the environment are not exceeded. An accurate determination of these levels, by using very sensitive analytical methods, will not then be required. Methods with a detection limit of approximately one-tenth of the appropriate specified level will often suffice.

4. ENVIRONMENTAL MONITORING PROGRAMMES

4.1. Programmes conducted in relation to discharges to atmosphere

Table I lists possible routes of exposure to populations living in the vicinity of a nuclear establishment from which radioactive wastes are released to the atmosphere.

The relative importance of these various routes depends, among other things, upon the composition and physical properties of the wastes discharged. Thus, from materials such as the noble gases, e.g. $^{85}$Kr, $^{41}$Ar, $^{133}$Xe, the dominant hazard is external irradiation of the whole body. Particulate materials such as uranium, which is poorly absorbed from the digestive tract or is not transferred through food chains, present primarily an inhalation hazard.

Radionuclides released to atmosphere as vapour or in particulate form may contaminate drinking water and food supplies, either directly or indirectly through a series of intermediary stages. Indeed, in many cases, the dominant hazard to members of the general public from discharges to the atmosphere will be from contaminated food. Therefore, information is frequently needed in order to assess the radi-
TABLE 1
RADIOACTIVE WASTES
RELEASED TO THE ATMOSPHERE

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<thead>
<tr>
<th>Path of Radiation Exposure</th>
<th>Description</th>
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<td>Ambient air → deposition on crops → immediate uptake by plants, or delayed uptake through soil → ingestion by man.</td>
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</tr>
<tr>
<td>Ambient air → deposition on crops → immediate uptake by plants, or delayed uptake through soil → ingestion by animals → transfer to animal tissues or organs → ingestion by man through milk, eggs or meat.</td>
<td></td>
</tr>
<tr>
<td>Ambient air → inhalation by man.</td>
<td></td>
</tr>
<tr>
<td>Ambient air → external irradiation of man, plants or animals.</td>
<td></td>
</tr>
<tr>
<td>Ambient air → deposition on land surface → secondary transfers to and irradiation of man through use of air, land or water.</td>
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Measurement of the concentration of specific radionuclides, for example, in air, or on the ground surface, will allow the approximate levels that may accumulate in foodstuffs to be predicted. The relationship between the contamination of the physical environment and the concomitant level in food can be interpreted with confidence only when the factors affecting movement from one to the other are sufficiently understood and, as knowledge has accumulated, it has become evident that this relationship is variable. The logical conclusion is that, when possible, food itself should be sampled and analysed.

The critical foods vary, depending on local agricultural practices and dietary habits and on the nuclides released. To take the example of the dietary pattern in the United Kingdom, the most important characteristics are that about 75% of the total dietary calcium, which is of biological origin, is usually obtained in dairy products, and milk is particularly important in the diet of children. The entire milk supply of a localized community, particularly in country
areas, may come from nearby farms, while many other foods are normally obtained through commercial channels largely from distant sources. Many nuclides are transferred in significant amounts from a cow's diet to its milk. Milk is therefore a foodstuff of particular importance when such nuclides are released under circumstances similar to those found in the United Kingdom, as, for example, in many countries in the western hemisphere. It must be emphasized that not all nuclides are transferred to milk in appreciable amounts. If such nuclides are released, materials other than milk, particularly fresh vegetables, must be considered. In other countries, because of different dietary habits, milk may be of little or no significance in any case, and other foodstuffs such as cereals, pulses, vegetables and, possibly, fish assume a position of importance.

As an example, a nuclear reactor located in a milk production area may be considered. Because volatile nuclides are likely to escape into the environment considerably more readily than other fission products, the critical nuclide is iodine-131. In seasons when cattle are grazing on open pastures, milk will be the critical food. The thyroid glands of infants fed on fresh milk may receive doses 20 times greater than those of adults - thus, young children constitute the critical population. If deposition occurs during the winter months, when cattle are under shelter, the risk will be very greatly reduced. Of the other fission products of possible importance $^{89}$Sr and $^{90}$Sr may be mentioned. Again milk will usually be the critical food, but under some circumstances cereals may arouse special concern. At other plants the other nuclides may deserve particular consideration. No generalization can be made — each situation should be considered on its own merit.

In the preceding paragraphs it has been assumed that the released radioactive material is in a freely soluble form so that it can enter readily into food chains. If, however, sparingly soluble materials are released, the maximum radiation doses may not occur until after the passage of an appreciable period of time during which the material is rendered soluble in the soil. This is important only with long-lived nuclides, for example, strontium-90. In such cases it will obviously be desirable to obtain information on the possible magnitude of risk in advance of its occurrence, and the examination of the critical food by itself will not provide this information. Where this type of situation is likely to occur it is, therefore, necessary to measure not only the critical food but also the total deposit on the ground surface.
Measurements to be made are decided on the basis of the principles set out in section 3.

The aim of the monitoring programme is not to determine the average radiation dose received by all members of the public who might be exposed to radiation as a result of the operations of the establishment, but rather to ensure that the exposure of the critical population does not exceed stipulated levels. Sampling sites should, therefore, be selected with this in mind: they should be situated, for example, in places where the air concentration or ground deposition is likely to be highest. Therefore, any environmental factors which might cause local concentrations of activity must be taken into account.

The number of sampling stations chosen depends to some extent on the material to be sampled. As an example, if milk is the critical food, herd samples provide an excellent indication of the situation over a fairly wide area, and such samples taken from up to perhaps ten farms surrounding the establishment will provide ample data. The factor which most often governs the choice of sampling stations is practicability; thus, there may not be ten farms available to sample, and it may be impossible to select farms in the right situations relative to the establishment or owners may not be co-operative. A compromise selection then must be made.

If it has been decided that information on the contribution of the establishment to the total contamination can be distinguished by carrying out a background survey, samples to be used to provide these background data must be obtained from areas which are unlikely to be affected by material released from the establishment. If the main extraneous contamination results from fall-out, better information on the contribution from this source can usually be obtained from any comprehensive fall-out survey that may be conducted in the area.

Two factors are important in determining the frequency with which measurements need to be made – the physical half-life of the nuclide under consideration, and its persistence in the medium of interest. If the period between measurements or samples is too long, the effects of sporadic releases of activity may be missed. On the other hand, very frequent sampling may overload the available analytical facilities. Therefore, a balance must be reached.

Since air concentrations fluctuate rapidly, measurements of external radiation levels from the presence of rare gases or of air contaminations need to be made frequently, or continuously. Although
continuous air sampling, with occasional measurement of the activity collected by the filter paper, will provide the most accurate assessment of the integrated contamination by inhalation of the members of the public in the vicinity, it will often be found that sampling at discrete intervals suffices.

Foodstuffs, such as leafy vegetables or milk, which become directly or indirectly contaminated as a result of the deposit of the released nuclides, or to the aerial parts of plants need to be sampled less frequently: milk, for example, is conveniently sampled every two weeks.

The activity concentration only changes slowly in foodstuffs contaminated through the uptake of deposited activity from the soil. The nuclides involved are almost inevitably long-lived, and infrequent sampling suffices. The radiation doses applicable to members of the general public are usually specified in terms of annual doses or annual intakes. In theory, therefore, a long-lived nuclide persisting in the environment might be considered to be adequately controlled by an annual measurement or an annual sample. In practice, however, it would probably be considered more prudent to take more frequent samples and to make more frequent measurements.

The number of analyses required can be reduced by the judicious bulking of samples. Bulking can be used as a means of integrating results from samples obtained from different sampling sites and/or at different times. The latter is satisfactory only for nuclides with a long enough physical half-life for decay of activity between the time of collection of the first sample and the time of analysis to be negligible, since it is otherwise impossible to correct adequately for radioactive decay.

When samples from a number of sampling stations are bulked the criteria against which the analytical results have to be compared will differ from the criteria applicable to single samples. If, for example, the milk from five farms were combined, the level of activity in the bulked sample would have to be less than one fifth of the level specified for a single sample to ensure that the specified level was not exceeded on any farm.

4.2. Programmes conducted in relation to discharges to bodies of water

The possible routes through which man can be exposed to irradiation as a result of discharge of radioactive wastes to rivers,
streams, lakes or oceans are many and varied and may be very complex. Tables IIA and B list the most important potential sources of hazard — they are not comprehensive.

<table>
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<tr>
<td>RADIOACTIVE WASTES RELEASED TO RIVERS, STREAMS AND LAKES</td>
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Contaminated water → ingestion by man.

Contaminated water → immediate uptake by plants and animals from water, or delayed uptake by plants and animals through sediments and aquatic food chains → ingestion by man.

Contaminated water → use for irrigation → immediate uptake by plants or plant roots, or delayed uptake through soil → ingestion by man.

Contaminated water → use for irrigation → immediate uptake by plants or plant roots, or delayed uptake through soil → ingestion by grazing or foraging animals → ingestion by man through milk, eggs or meat.

Contaminated water → accumulation on mud, sand or beaches → use for swimming, boating or skiing or fishing → external irradiation of man, either directly or by contamination of equipment.

It is evident from Table II that it could be quite wrong to use criteria applicable to drinking water as standards for radiological control under all circumstances.

When wastes are discharged to rivers or to lakes, it is usually found that drinking water, foodstuffs irrigated with contaminated water or, sometimes, fish, are the main routes of exposure.
TABLE II B

RADIOACTIVE WASTES RELEASED TO THE OCEAN

Contaminated water $\rightarrow$ immediate uptake by plants and animals from water, or delayed uptake by plants and animals through sediments and marine food chains $\rightarrow$ ingestion by man.

Contaminated water $\rightarrow$ accumulation on mud, sand, beaches or tidal flats $\rightarrow$ immediate uptake by plants and animals from water, or delayed uptake by plants and animals through sediments and marine food chains $\rightarrow$ ingestion by man.

Contaminated water $\rightarrow$ accumulation on bottom sediments $\rightarrow$ contamination of fishing gear or other equipment $\rightarrow$ external irradiation of man.

Contaminated water $\rightarrow$ accumulation on mud, sand or beaches $\rightarrow$ use for boating, swimming or skiing $\rightarrow$ external irradiation of man.

Thus, the critical population established in connection with discharges to the River Thames from U.K.A.E.A. establishments is that part of the population of London which obtains its drinking water from the river. On the other hand the potentially most hazardous route of exposure, resulting from the discharge of corrosion products from the power station in Trawsfynydd in Wales to a fresh-water lake, has been identified as the consumption of trout.

Wastes discharged to the sea present a more complex problem but, in general, the three processes which prove to be of importance are the contamination of edible marine organisms, contamination of sea bed and hence of fishing-gear etc., and contamination of beaches.

Some idea of the variety of routes of exposure that have been found to need routine surveillance may be gained by consideration of United Kingdom establishments which discharge to the sea. From the nuclear-power stations, Bradwell, Berkeley and Hinkley Point,
the important nuclides discharged are the corrosion products, $^{65}\text{Zn}$, $^{60}\text{Co}$, and $^{124}\text{Sb}$. There are oyster beds near Bradwell and oysters are known to concentrate $^{65}\text{Zn}$ from sea water; the critical nuclide in this case is therefore $^{65}\text{Zn}$ and the critical material, oysters. At Berkeley and Hinkley Point the critical materials have proved to be fish and silt – the latter because local fishermen spend many hours on the silt of an estuary operating fixed fishing engines. Fishermen are again the critical population at the experimental reactor establishment at Dounreay, but here because detritus contaminated with $^{95}\text{Zr} / ^{95}\text{Nb}$ has been found to adhere rather tenaciously to their nets. Both fishing gear and local consumption of lobsters have had to be considered at the Winfrith atomic energy establishment; long-lived fission products are important here. Finally, at the fuel reprocessing plant at Windscale, the critical nuclide is $^{106}\text{Ru}$; the critical material an edible seaweed, which is collected local to the establishment; and the critical population a fairly small group of people living in Wales, far from the establishment.

The factors governing the selection of sampling sites, frequency of sampling and bulking of samples are essentially the same as those outlined in section 4.1. When discharges into a river or stream take place, and water is to be sampled, it would in many ways seem best to take samples from the point where water is withdrawn for drinking purposes or for irrigation. However, the effluent may have become so diluted by this time that its activity is not readily measured and, although samples taken at the point of withdrawal are useful for public relation purposes, samples to be used for radiological control are probably better taken from near the point of discharge. Sampling stations should then be sufficiently far downstream from the discharge point to ensure that the effluent has been dispersed. An estimate of the activity added to the river from an establishment can be obtained by comparison with samples taken from upstream above the discharge point.

Edible products from rivers or the sea may be collected especially for monitoring purposes or may be obtained by sampling the harvest gathered by commercial fishermen etc. In the latter case care should be taken that the origin of the material sampled is known.

In general, very short-lived nuclides are of little concern as contaminants of drinking water. When discharges are more or less continuous, weekly sampling will, therefore, usually suffice. These samples may be bulked for less frequent analyses if the half-life of the important nuclides so permits. If discharges are intermittent,
sampling near the point of discharge can be limited to the period immediately following a discharge.

The concentration of a nuclide in organisms such as fish, and in materials such as sand is not subject to rapid fluctuations since it reflects the accumulation of the nuclides over a period of at least several days. Such organisms and materials do not, therefore, need to be sampled very frequently – monthly or three-monthly sampling may be considered adequate, depending upon the particular circumstances.

4.3. Programme conducted in relation to discharges to the ground

Liquid wastes may be poured directly into the ground or, more commonly, radioactive solid wastes may be buried, contained or uncontained, below the ground surface. The possible routes of return of such activity to man are much the same in either case and are outlined in Table III.

Most of the hazards listed in Table III can be rendered insignificant by the suitable management and choice of the disposal site. The greatest potential hazard remaining is undoubtedly the pollution of water as the result of activity leaching from the waste into either surface or ground water. Control can, therefore, be most successfully exerted by examining water samples from streams draining from the disposal area or, where necessary, from wells or boreholes sunk around the periphery of the site. If water supplies become contaminated a programme may need to be developed along the lines indicated in section 4.2.

4.4. Discharge-point monitoring

It is evident that, certainly initially, it would be unwise to attempt management of the situation solely on the basis of the amount of activity released to the environment. Although an estimate can be made of the radiation doses to which individuals in the population may be exposed as a result of the discharges, the uncertainties necessarily involved in the calculation render such an estimate approximate. Control should, therefore, be based, as far as practicable, upon measurements made on those materials which are the source of exposure. As experience accumulates it may be possible to reduce the number of environmental measurements and even, at an appropriate stage, to rely entirely on control by monitoring waste
TABLE III

RADIOACTIVE WASTES
RELEASED TO THE GROUND

Contaminated soil → subsequent leaching by infiltration of surface water → immediate or delayed entry into ground water → subsequent recovery in wells → ingestion by man.

Contaminated soil → subsequent leaching by infiltration of surface water → immediate or delayed entry into ground water → movement with ground water to surface outcrops → secondary transfers and irradiations similar to those associated with releases to rivers, streams and lakes.

Contaminated soil → uptake by deep-rooted plants or burrowing animals → secondary transfers and irradiations similar to those associated with releases to the atmosphere.

Contaminated surface soil → transfer to rivers, streams or lakes by sediment transport during floods or rapid run-off → secondary transfers and irradiations similar to those associated with releases to rivers, streams and lakes.

Contaminated surface soil → transfer to the atmosphere by wind pick-up → secondary transfers and irradiations similar to those associated with releases to the atmosphere.

before or during discharge. This step can only be taken if environmental measurements are such as to allow the establishment of an empirical relationship between the discharge rate of a nuclide and its concentration in the material of interest.

Because the samples are taken from a point where the contaminant is still at a relatively high concentration before its discharge and dispersion, they are easy to analyse and the sampling system can be made extremely sensitive, enabling small changes to be detected.
For the same reason, there is no need for extensive chemical ana-
lytical facilities, and in some cases simple chemical measurements
are sufficient to determine the quantity of material in the sample.
A further advantage is that trends and levels not yet significant
to health can be detected easily, and small abnormal releases can
also be detected at levels well below those which could be hazardous.

5. SELECTION OF ENVIRONMENTAL
MONITORING PROCEDURES

5.1. General remarks

This section attempts to give guidance on the selection of
methods of sampling and measurement: detailed descriptions of the
methods are available in other texts given in the list of references.
Two basic principles should be borne in mind; (i) the method used
must allow the potential hazard to be evaluated; and (ii) the method
should be the simplest that will enable this objective to be achieved.

5.2. Air monitoring

There are two general methods of collecting air samples – contin-
uously or intermittently. Continuous sampling may be combined
with continuous measurement. The sampling stations may be fixed
or mobile.
As part of a programme intended for radiological control, air
sampling is strictly only necessary for evaluation of any potential
hazard existing from the inhalation of a vapour or particulate ma-
terial. Such a situation may develop, for example, in the vicinity of
a uranium-processing plant.
If noble gases are released the situation in the environment could
be assessed by making continuous measurements of their concen-
trations in air but, since they primarily irradiate the whole body,
the radiation doses received by exposed persons are better estimated
by using normal beta/gamma monitoring instruments.
If, on the other hand, mixed fission products are released to the
atmosphere, the dominant hazard to the public will almost certainly
be through contaminated food, and air contamination itself will be
relatively insignificant. As explained in section 4.1, the situation is then best controlled by examining the foodstuff of interest.

In most cases, when air sampling is necessary, simple air samples with fixed filter papers are adequate.

Fixed air-sampling stations are frequently used around establishments that present no hazard to the general public through airborne contamination under normal operating conditions. Air sampling in this case, and in the sense that the term is used in this manual, is used more as a means to satisfy the management of the establishment that it is operating satisfactorily than as part of an environmental monitoring programme.

Mobile samplers are the most economical in use. If it is planned to provide a vehicle equipped with both sampling and measuring equipment for use in pre-emergency surveys and for monitoring after an accidental release, some economy can be made by using the sampler routinely. It must be remembered, however, that the measuring techniques required as part of a routine survey or of an emergency survey differ somewhat and, for routine work, it is probably preferable to arrange for the filter papers to be examined in the laboratory.

5.3. Water monitoring

As with air, water can be sampled either intermittently or continuously. Alternatively, instruments for detecting radiation may be arranged in or over the body of water to allow a continuous estimation of the activity concentration in the water. Water itself generally needs to be sampled only when it is used for drinking purposes and occasionally when used for irrigation. Other materials, through which members of the public may become exposed as a result of the presence of radioactive material in water, are themselves best examined rather than the water which leads to their contamination.

As explained in section 4.2, when discharges are made to rivers and streams, intermittent sampling usually suffices. Specialized sampling techniques are not required and all that is needed is to ensure that the sample is representative. There may be an occasion when continuous sampling is considered desirable, but it is seldom necessary for the purpose of radiological protection. Various devices exist which enable a known fraction of the total volume of water flowing along the water-course to be collected continuously. (See Refs.)
5.4. *Foodstuffs*

The main problem when examining foodstuffs is to obtain a representative sample. Fortunately the materials which need frequent surveillance, namely milk and cereals, are easily mixed before sampling. Details of sampling techniques are given in the FAO Atomic Energy Series No. 4.

5.5. *Miscellaneous materials*

Herbage and soil need to be sampled by specialized methods, both to ensure that the samples taken are representative and to avoid cross-contamination. Details of techniques are given in the FAO Atomic Energy Series No. 4.

Materials such as silt or sand on beaches, or detritus on fishing nets, which are primarily a source of external radiation, can be controlled by the measurement of their nuclide content, if a relationship can be established between the dose rate from these materials and their radioactivity content, or by direct measurement of the dose rate from the material at a distance considered appropriate to the mode of exposure, using suitable dose-rate measuring instruments.

6. REQUIREMENTS OF MANPOWER AND EQUIPMENT

6.1. *Manpower*

The operation of a routine survey programme embraces a number of activities from designing the survey, directing the survey, collecting samples, and analysing samples, to collating and interpreting the data obtained. Professional advice from many sources may be required during the planning phase and at least one professionally trained scientist is needed to supervise the programme in its initial stages. As experience accumulates many of the survey operations are reduced to repetitive routines, and less of the specialist's time will be required so that he may be able to assume other duties and responsibilities. The scientist in charge of the survey should have an understanding of, and access to advisers in, sampling techniques, operation and maintenance of nuclear counting equip-
ment, qualitative and quantitative chemical analyses, statistical evaluation of data, nuclear and radiation physics 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 if samples from the field are to be properly collected and analysed according to specialized procedures.

6.2. Equipment

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 greater than if, for example, 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.

Unless numerous results are accumulated, special data-processing methods are not required since the endeavour should always be to keep the number of samples and analyses, and hence the number of results, to the minimum necessary to ensure adequate control.
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ENVIRONMENTAL MONITORING IN THE AREA
OF THE CADARACHE NUCLEAR STUDIES CENTRE

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INTRODUCTION

The Cadarache Centre is part of the French nuclear programme providing for extensive development of research and, hence, of personnel and installations.

The site was chosen because of a number of factors, the main ones being that there had to be sufficient water available for cooling the installations, and that the ground had to be sufficiently firm to support the heavy weight of the reactors, laboratories and workshops. Other factors were also involved; e.g. the area selected had to be of relatively low agricultural importance without being completely cut off from large urban centres. Another favourable feature is that the site is close to university towns: this will stimulate the development of joint research with the Centre.

The Cadarache site, chosen on the basis of these geological, geographical, economic and human parameters, is situated in the commune of Saint-Paul-lez-Durance, Department of Bouches-du-Rhône, near the confluence of the Durance and the Verdon. It is not far from Manosque and only 35 km from Aix-en-Provence and 60 km from Marseilles (see Figs. 1 and 2 at the end of this book).

It has an area of 1600 hectares, 700 of which can be used for building purposes.

DESCRIPTION OF THE ESTABLISHMENT

Cadarache is essentially a centre for testing prototype reactors intended for use in power stations or for ship propulsion. In addition, experimental studies are carried out in connection with reactor structural materials and fuel elements, and various studies related
to reactor physics, radiation protection, plant biology etc., are also undertaken.

Regarding the Centre's equipment and programmes of work, reference should be made first of all to the Pégase and Rapsodie reactors.

Pégase, which reached criticality in April 1963, is a swimming-pool-type reactor in which full-scale testing of the fuel elements of gas-cooled power reactors moderated by graphite or heavy water can be carried out. The reactor block comprises a core operating with 90% enriched uranium, used as a neutron source, and submerged loops, cooled by pressurized carbon dioxide, containing the elements to be tested.

The maximum thermal power is 30 MW. Containment is by means of a shell with leak control by ventilation including high efficiency dust filters and iodine traps.

Rapsodie (in course of construction) is a sodium-cooled, fast-neutron experimental breeder reactor.

The fuel is a mixture of oxides of uranium and plutonium. The planned thermal power is 20 MW. The building housing the reactor consists of a leak-proof metallic shell.

The Cadarache Centre also includes enriched uranium processing shops for the chemical conversion of uranium hexafluoride and for the recovery of enriched uranium, and an irradiated fuels laboratory where measurements are carried out on fuel elements irradiated in the experimental reactors (mainly in Pégase), and tests are made on samples prepared from irradiated fuel elements. The "hot" area of this laboratory comprises ten cells, including five 100,000-Ci cells. In addition, there is a plutonium-technology shop where fuel elements are fabricated from plutonium in partitioned cells. Special ventilation isolates the cells from the building, and the building from the outside.

DESCRIPTION OF THE SITE

Hydrology

The waters of the Durance and the Verdon are retained upstream from the site by the Cadarache dam and diverted via an industrial canal to supply the Jouques hydro-electric station. The Centre takes the water required for operating its installations from the industrial
canal but discharges waste water into the Durance, where a minimum flow rate is continually maintained. The industrial canal, which forms part of the programme for operating a chain of four power stations, supplies several large towns (including Marseilles) with drinking water and recharges agricultural canals over an area stretching almost as far as the Rhône. Downstream from the Centre's discharge point the Durance is still used by various communities either for drinking water, via the water table, or for irrigating areas where the agricultural canals are not recharged, particularly below Mallemort.

Meteorology

The wind speed is usually low near the ground. The prevailing directions are west and south-east and the local winds (valley breezes) have a predominating influence. Temperature inversions are very frequent. The rainfall varies greatly from one year to another (400 - 800 mm), and often takes the form of stormy showers.

The local ground relief (network of valleys and anticlinal folds) and vegetation (Mediterranean-type forest) strongly influence the ordinary behaviour of the air with respect to the diffusion of an atmospheric effluent.

To determine precisely this influence, full-scale experiments are being carried out using fluorescent tracers. The tracking of calibrated balloons by radar provides statistics regarding trajectories in any kind of weather, and by co-ordinating the test it will be possible to shed light on certain atmospheric diffusion experiments.

Four meteorological posts and a 110-m pylon constitute the equipment required for climatological and microclimatological studies.

Human geography

The population is not very dense (20-30 inhabitants per square kilometre and the hills are generally uninhabited (see attached map: Fig.2).

From the agricultural point of view, there is market gardening and fruit growing, but this is limited to the Durance valley and there is practically no dairy farming. Irrigation is traditionally by means of canals and channels, but sprinkling is becoming more and more widespread, especially on large holdings.
HAZARDS ASSOCIATED WITH NORMAL OPERATION OF THE ESTABLISHMENT

These hazards are essentially due to the emission of liquid and atmospheric radioactive effluents.

Liquid effluents may have two origins:

1. Reactor liquid effluents, not containing many salts and decontaminated by evaporation, which may contain activated products of corrosion and fission products resulting from micro-ruptures of cans and the initial external contamination of fuel.

2. Liquid effluents from the processing of uranium and plutonium, and ordinary laboratory or workshop effluents, which may contain uranium, plutonium, or fission products, and which must undergo chemical decontamination.

The effluents are transported by special trucks from the installations to a processing plant. The decontaminated water is stored in individually-monitored batches. Analytical tests are mainly for radium, uranium, strontium-90, caesium and cobalt. After dilution, the effluents are discharged into the Durance in conformity with regulations established in conjunction with the competent public authorities.

Gaseous effluents - carbon dioxide discharged from the chimney of Pégase, mainly during loop deflation operations - may possibly be contaminated by fission products from can ruptures.

In addition, volatile fission products (in particular iodides) may be released when the fuel elements are stripped.

However, the cooling times are such that the operations cannot lead to significant atmospheric contamination.

Finally, solid wastes are treated and stored on site to prevent any significant dispersion of radioactive contamination.

MONITORING PROGRAMME AND METHODS ADOPTED

The monitoring programme has three purposes:

To check the environmental contamination due to normal operation of the installations, special attention being paid to the principal paths by which contamination reaches man. Since this is related to the use of the water of the Durance for drinking and irrigation downstream from the Centre, the contamination of the water itself must be monitored together with that of commodities manufactured.
from crops irrigated by canals or by sprinkling. The hazards accruing from gaseous effluents are less, and are due to deposition on market-garden or fruit crops.

To check the environmental contamination due to processes not connected with the operation of the Centre (natural radioactivity and fall-out from nuclear tests). The reference measurements made before start-up of the installations are continued in areas which, although in the neighbourhood, cannot be affected by the operation of the Centre (e.g. basin of the Durance above the Centre).

To check the variations in $\gamma$-irradiation in areas which might be affected by an accident at the Centre, so as to be able to rapidly determine any contaminated zone.

It is also necessary to have available the data required for describing the natural dispersion vectors, both from the "climatological" point of view (average and most likely behaviour, as established statistically over a long period of observation) and from the "operational" point of view (momentary behaviour, established by permanent monitoring facilities). For example, in the case of water, data on liquid and solid flow-rates in the Durance and in the industrial canal and on operation of the Centre's drainage network; in the case of air, data on wind directions, wind-speed spectra, trajectories, atmospheric diffusion conditions, precipitation data, etc.

The implementation of this programme involves various procedures such as the operation of permanent stations, mobile sampling and analysis facilities, a 110-m-high pylon and a routine laboratory for total radioactivity measurements. The radiochemical and spectrographic analyses are carried out by the central laboratory of the Radiation Protection Department.

**Atmospheric monitoring**

There is a central station, known as Grande Bastide, with a 110-m-high metal pylon. Three other stations, La Verrerie, Saint-Paul-lez-Durance and Ginasservis, none of which are more than 6 km from the Centre, are used for monitoring the neighbouring villages (Vinon, Saint-Paul and Ginasservis). At these stations measurements are made of $\gamma$-irradiation and of $\alpha$- and $\beta$-contamination by aerosols and gases. One station, La Verrerie, is used for measuring dry or liquid fall-out.

In addition, the stations are associated with fully equipped meteorological posts which provide the basic data necessary for
climatological studies and which can supply, if required, information of importance in connection with the interpretation of various radioactivity measurements.

The 110-m-high pylon is equipped for measuring winds and vertical temperature gradients, and can thus furnish data on probable atmospheric diffusion conditions.

Wind measurements at high altitude are made at least once daily by pilot balloons.

Vehicles, including two Land Rovers, are being fitted out as mobile stations and will carry out continuous monitoring of irradiation and contamination. Two 2-CV Citroëns, which are more mobile, are fitted with simpler equipment.

Figure 3 shows the various monitoring points served by these vehicles.

All the contamination measurements are made for total $\alpha$- and $\beta$-activity. The daily atmospheric filters (grouped together by weeks), the rain samples and the fortnightly atmospheric samples taken on activated charcoal, are also subjected to regular $\gamma$-spectrometry.

**Monitoring of water**

There are three stations, Mirabeau, Mallemort and Bonpas, situated at intervals along the Durance within a distance of 70 km downstream from the Centre. Two others, Pompage (pumping) and Rejets (waste), monitor the water entering and leaving the Centre. A station is also being built at the edge of the industrial canal near the Jouques hydro-electric station.

Each station is equipped with one or more radioactivity detectors and a fractional sampling device.

In addition, series of measurements and systematic discontinuous sampling outside the permanent stations (see Figs. 3 and 4 at the end of this book) are performed weekly at 14 points along the industrial canal, the Durance and its permanent or temporary tributaries, monthly at seven points on the water table (wells, bore-holes, springs), and quarterly at 10 points on tanks containing water for fighting forest fires.

All the water samples are analysed for total $\alpha$- and $\beta$-activity.

In addition, measurements are made for pH, resistivity and fluorescence, and content of Na, K, Ca is determined by flame-photometry.
The samples are subjected to radiochemical analysis when the total $\beta$-level is abnormal. These analyses are carried out regularly on water continuously sampled at the Mirabeau station. Particular attention is paid to uranium, thorium, $^{90}\text{Sr}$ and $^{137}\text{Cs}$.

**Monitoring of vegetation**

Plants used for human consumption are monitored in respect of the two basic paths of transmission of contamination: irrigation networks and the atmosphere. The plants sampled every month in the basin of the Durance above and below the waste-disposal points include lettuces, cabbages, cauliflowers, spinach, artichokes, carrots, turnips, potatoes, pumpkins and marrows, tomatoes, melons and aubergines. Likewise, vegetables and fruit are gathered for monitoring purposes in the normally downwind areas near the Centre. Total $\beta$-activity and activity of $^{89}\text{Sr}$, $^{90}\text{Sr}$ and $^{137}\text{Cs}$ are determined.

The monitoring of total $\beta$-radioactivity is also done half-yearly on evergreen plants (Aleppo pine, holm oak, thyme) at six points near the Centre's installations. These checks can yield reliable data on fall-out and thus indicate whether the nuclear installations are operating safely and properly.
ANNEX II

ENVIRONMENTAL MONITORING AROUND THE NUCLEAR RESEARCH CENTRE AT LA CASACCIA, ITALY

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CASACCIA CENTRE FOR NUCLEAR STUDIES, ITALY

1. DESCRIPTION OF THE INSTALLATION

(a) Brief technical description

The Centre for Nuclear Studies at la Casaccia (Centro di Studi Nucleari della Casaccia), which is affiliated to the National Committee for Nuclear Energy (Comitato Nazionale per l'Energia Nucleare), is situated 25 km to the north-west of Rome and covers 65 hectares. It consists of a number of facilities and laboratories for research into the uses of nuclear energy. It is divided into eight areas:

Reactor area

At present this comprises: the 100-kW RC-1 reactor (Reattore Casaccia 1), type TRIGA Mark II; a 400-keV Van de Graaff linear accelerator; the 10-kW light-water-moderated Ispra-2 reactor (called RANA), with MTR fuel elements; and the organic-moderated, experimental, zero-power reactor ROSPO.

The construction of a large metallurgical reactor is envisaged for the future and the power of the TRIGA reactor is to be increased soon to 1 MW.

Laboratory area

This comprises laboratories for Reactor Technology, Servo-Mechanisms and Reactor Physics.
Electronics laboratory area

Metallurgical area: This comprises the Hot Cells Group and laboratories for Metallurgy, Industrial Chemistry and Ceramics Technology.

Treatment area: In this area are housed the plant for the treatment of radioactive waste and conventional waste, the decontamination centre and the conventional scrubbing plant;

Geological and Mining area: This comprises laboratories and administrative offices of the Geological and Mining Division.

Biological area: This comprises laboratories of the Biology and Health Protection Division, the gamma field, greenhouses and fields used for experiments in agriculture.

General services area: This comprises the entrance to the installation, the main administrative offices, the Secretariat, power plant, water-supply service and the canteen.

(b) Description of the site

Geological characteristics: The region in which the Centre is situated forms part of the Sabatine volcanic region.

The principal geological materials of the region are (descending):

1. Cinder, scoria, loose or slightly clinkered lapilli - with gradual transition to
2. Loose basaltic and leucitic tufa;
3. Loose ferrous tufa and mainly brachytic elements, loose brown tufa with a predominance of augite;
4. Basaltic and markedly leucitic lava;
5. Yellow tufa and sand with numerous intercalary paleosols.

A microscopic examination of samples obtained by boring revealed the following geological evolution of the region (ascending):

1. Lacustrine deposits (in the north) with occasional drifts of volcanic material;
2. Several (at least two) successive lava flows;
3. The accumulation of pyroclastic products and the simultaneous formation of new lacustrine deposits.

Meteorological characteristics: La Casaccia forms part of the Central Tyrrhenian climatic zone and the moderating effect of the sea is therefore evident, particularly with regard to temperature. The influence of the maritime climate is also felt in the air movements, producing a well-defined system of winds predominantly from
the north and south-south-west. The north winds predominate absolutely, as can be seen from the attached compass card. These winds have an average speed varying from 6 to 35 km/h and may reach peaks of 85 km/h in March and November (see Fig. 1).

![Surface wind rose](image)

**FIG. 1.** Surface wind rose (1961 - 1962 average), C. S. N. Casaccia

It should be noted that the stable conditions, i.e. those which are the least favourable to atmospheric diffusion, generally coincide with the north winds, which blow in the direction of regions with extremely low population density.

**Population distribution:** (See Fig. 2) The principal centres of habitation in the region surrounding the Centre at la Casaccia are as follows:
### Centre of habitation | No. of inhabitants | Distance (km) | Direction
--- | --- | --- | ---
Trevignano | 2013 | 13.5 | N
Anguillara | 3226 | 6.5 | N
Cesano | 2438 | 6 | NE
Formello | 2058 | 9.2 | NE
Campagnano di Roma | 3922 | 13 | NE
Sacrofano | 1713 | 14 | NE
Isola Farnese | 291 | 7.5 | E
Osteria Nuova | 170 | 0.8 | SE
S. Maria di Galeria | 97 | 2.3 | SE
La Storta | 926 | 8 | SE
Proccietto | 116 | 6.5 | S
Cornazzano | 50 | 3.2 | SW
Tragliata | 60 | 8.5 | SW
Torrimipieta | 216 | 14 | SW
Vigna di Valle | 39 | 7.5 | NW
Bracciano | 10478 | 12.5 | NW
2. SOURCES OF RADIOACTIVE WASTE MATERIALS
(Solids, liquids, air pollution)

At present solid radioactive waste consists of articles, pieces of equipment, rags, glass, animals, etc., contaminated as a result of the operation of the hot cells, and of the Triga and Rospo reactors, or of work done in the metallurgy and industrial chemistry laboratories and, to a small extent, the biology laboratories.

The waste materials are placed in metal drums lined with polyvinyl chloride. These are stored in a covered enclosure until such time as the plant for treating solid waste comes into operation.

Liquid waste (washing and drainage effluent, chemical laboratory waste, etc.) originates mainly in the hot cells, the Triga reactor, the Rospo reactor and the metallurgy and industrial chemistry laboratories. The liquid waste is normally stored in special tanks and then conveyed to the liquid-waste treatment plant. After decontamination the liquid is drained from the installation and, after radiometric checking by the Radiation Control Service, is discharged into the Fossetto, a small stream which runs alongside the Centre.

Under normal working conditions there is at present no large source of gaseous waste. Only small quantities of gaseous or powdery waste may possibly escape from the Rospo reactor, the hot cells or the chemical laboratories (fission products, Pu, U, Th).

The above applies to normal conditions.

Under abnormal conditions caused by an accident the sources of emission may be as follows:

<table>
<thead>
<tr>
<th>Installation</th>
<th>Type of accident</th>
<th>Type of emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triga reactor</td>
<td>Break in the primary circuit</td>
<td>Water from the primary circuit</td>
</tr>
<tr>
<td>Triga reactor</td>
<td>Maximum credible accident</td>
<td>Fission products</td>
</tr>
<tr>
<td>Rospo reactor</td>
<td>Maximum credible accident</td>
<td>Fission products</td>
</tr>
<tr>
<td>Hot cells</td>
<td>Fire</td>
<td>Fission products, uranium</td>
</tr>
<tr>
<td>Metallurgy laboratories</td>
<td>Fire</td>
<td>Uranium, thorium</td>
</tr>
</tbody>
</table>
3. MONITORING PROCEDURES

**Environmental monitoring of radioactivity inside the Centre (see Fig. 3)**

(1) Fixed control stations

The setting-up of four fixed-control stations within the Centre perimeter has been decided upon. These stations contain the following instruments:

- One air-suction pump for collecting dust, equipped with fixed filter and an activated carbon cartridge for detecting $^{131}$I;
- One air-suction unit for collecting dust, equipped with moving filter and instruments for measuring and recording beta and alpha activity (continuous alpha, beta monitor);
- One gamma background counter with ionization chamber or Geiger-Müller counter and recorder;
- One receptacle for collecting fall-out;
- Pocket dosimeters and film badges for measuring gamma re-exposure.

Frequency of sampling:
- Fixed dust filter - daily;
- Carbon cartridge - weekly;
- Pocket dosimeters - monthly;
- Film badges - bi-monthly;
- Fall-out - monthly.

(2) Points for the sampling of fall-out

There are 12 points at which sampling for fall-out is carried out. These are as follows:

- 4 in the fixed-control stations;
- 1 on the hot-cells building, near the chimney stack;
- 6 around, and at a short distance from the metallurgy and industrial chemistry laboratories;
- 1 to the north of the Reactor Area, at the highest point in the Centre.

Frequency of sampling - monthly or as required.
FIG. 3. Map of C. S. N. Casaccia with monitoring stations

* Monitoring stations
(3) Points for sampling grass and earth

The Centre is divided into 12 sectors in each of which a series of samples of earth and grass are taken. These are then mixed so as to obtain a representative sample for each sector.

Sampling is carried out annually in each sector by rotation, each month in a different sector.

(4) Points for the sampling of effluent

One sampling point is the Fossetto, which runs along the western edge of the Centre, downstream from the outlet mains from the Centre.

Sampling is carried out daily and measurements are made each week on the basis of the average sample for the week. The installation of a continuous monitor is envisaged.

One sampling point is at the final collecting basin where all the drains meet before entering the septic tanks.

Sampling is carried out daily and measurements are made each week on the basis of the average sample for the week. The installation of a continuous monitor is envisaged.

(5) Background monitoring

Monthly monitoring of the gamma background by means of portable instruments is envisaged.

Environmental monitoring for radioactivity outside the Centre

(1) Points for sampling atmospheric dust

Santa Maria di Galeria: A centre of habitation downwind from the Centre under prevailing wind conditions, 2 km to the SSE;

Borgo Testa di Lepre: A centre of habitation downwind from the Centre under prevailing wind conditions 9 km to the SSW;

Anguillara: A centre of habitation 6 km to the NNW;
*Gare de Cesano: A centre of habitation downwind from the Centre under prevailing wind conditions, 3 km to the NE;

*Bracciano: A centre of habitation 12 km to the NW;

*Rome: Urban centre 22 km to the SE.

At all these points sampling of atmospheric dust is carried out by fixed-filter suction pumps. Sampling is carried out daily.

(2) Points for sampling surface water

Lake Bracciano
Lake Martignano
The River Arrone, at Ponte Valle Trave,
       at Pratino, and
       at Maccarese
Fossetto de la Casaccia (the stream of La Casaccia),
The River Tiber, at Rome.

Monthly samples comprising two litres of water are taken at each of these points. At some of the more important points, i.e. those more directly affected by effluents from the Centre, samples of silt and sediment are taken every six months.

(3) Points for sampling fall-out

Anguillara, Borgo Testa di Lepre, and Gare de Cesano.
Monthly sampling at each point.

(4) Points for sampling earth and grass

There are six of these within a radius of 2 km; they follow the pattern given below:

* To be installed in the near future.
<table>
<thead>
<tr>
<th>No.</th>
<th>Distance from the Centre (km)</th>
<th>Direction</th>
<th>Time of sampling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>SW</td>
<td>April</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>SE</td>
<td>May</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>S</td>
<td>June</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>N</td>
<td>July</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>S</td>
<td>September</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>NE</td>
<td>October</td>
</tr>
</tbody>
</table>

At each point annual sampling is carried out over an area of 15 to 20 m², which is enclosed so as to ensure that the soil and vegetation are not subject to changes.

(5) Points for sampling milk and fodder

Samples of milk are taken each month at five dairy farms located as follows:

Farm

- Centro Bandita - 1.5 km to the SSW
- S. Teresa - 1.5 km to the SE
- Centro Cesano - 3 km to the NW
- Casale S. Brigida - 1.5 km to the W
- Cacci - 3 km to the N

At each sampling samples of fodder consumed by the animals during the milk-sampling period are also taken (grass or dry fodder according to the time of year).

(6) Points for sampling cereals

Each year, during the threshing season, samples are taken of wheat from three regions lying:

- To the S of the Centre at a distance of 1-2 km;
- To the N of the Centre at a distance of 1-2 km;
- To the NW of the Centre at a distance of 1-2 km.
(7) Other sampling

The following samples are taken sporadically, or during the harvest: barley, oats, vegetables, fruit.

Sampling of varying frequency is also envisaged for bones, meat, thyroids of cattle, rabbits, chickens and lake and river fish.

(8) Also envisaged are checks on the gamma background within a radius of 5-10 km of the Centre, to be carried out at least once every three months.

*Types of measurement carried out on samples taken from points in the monitoring network*

(1) Atmospheric dust

Total beta activity;
Total alpha activity;
$^{131}$I (in the fixed control stations inside the Centre), with measurement of gamma activity using an activated carbon cartridge.

(2) Surface water, silt and sediment

Total beta activity (less activity contributed by $^{40}$K);
Total alpha activity (inside the Centre only);
Chemical determination of the potassium content.

(3) Fall-out

Total beta activity;
Total alpha activity (inside the Centre only).

(4) Milk and fodder

Gamma spectrometry;
Determination of $^{131}$I and $^{40}$K by spectrometry;
Determination of $^{137}$Cs by spectrometry or by using a chemical separation method (e.g. phosphomolybdate);
Determination of $^{90}$Sr by nitric acid separation, followed by measurement of the beta activity of the $^{90}$Y thus separated.
(5) Grass, earth, cereals

Gamma spectrometry;
Determination of $^{40}$K by gamma spectrometry;
Determination of $^{137}$Cs by gamma spectrometry, or by a chemical separation method (e.g. phosphomolybdate);
Determination of $^{90}$Sr by nitric acid separation, followed by measurement of the beta activity of the $^{90}$Y thus separated;
Examination for U, Th, etc. (inside the Centre only).

(N.B. Whenever it is considered necessary, all samples undergo measurement by gamma and alpha spectrometry and are subjected to radiochemical analysis to determine other radio-nuclides).

4. ENVIRONMENTAL MONITORING PROGRAMME

Under present operating conditions — low-power reactors, hot laboratories where only limited quantities of radioactive material are handled — and in the absence of large fuel-processing plants, the amount of radioactive waste and effluent produced by the Centre is normally extremely low.

It may be concluded from a study of the safety reports for the various reactors and facilities that the consequences of possible accidents would also be very limited.

It was therefore decided that the monitoring network should have a radius of about 20 km. The criteria on which the choice was based concerning the number and positioning of control stations and sampling points, were established after an examination of the prevailing meteorological situation, the distribution and density of the population, and the agricultural characteristics of the region around the Centre.

Control stations were set up in each centre of habitation of any size within a radius of 20 km. Other stations have been set up, some outside the centres of habitation, at points where — because of their position with respect to the Centre and the prevailing winds — the mean annual probability of contamination is greatest. It can be seen from Fig. 4 showing the sampling points that the greatest density of control stations is to the south and north-north-east of the Centre.
Samples of water are taken at three points in the River Arrone at different distances from the Centre; the reason for this is that the Fossetto de la Casaccia, into which the effluent from the Centre is discharged, is a tributary of this river. Samples are taken from Lakes Bracciano and Martignano and from the River Tiber for purposes of comparison.
Figures 5 and 6 show graphs of long-lived radioactive fall-out and long-lived airborne particulate radioactivity as measured at Casaccia.
FIG. 6. Long-lived airborne particulate radioactivity, C. S. N. Casaccia (monthly mean concentration)
1. INTRODUCTION

There are installed at Chapelcross four of the Calder Hall-type of nuclear reactors. Construction of the station commenced in 1955 and the first of the reactors reached power in January 1959 and the fourth in April 1960. Apart from laboratory provisions for technical investigations concerned with the reactors and research in health physics, Chapelcross, in essentials, differs little from the nuclear-power stations which are being built for the South of Scotland Electricity Board and the Central Electricity Generating Board. Since also, unlike Calder Hall which is closely integrated with Windscale, it is not associated with other atomic energy operations, the performance of Chapelcross from many aspects, including that of radiation hygiene, serves as a useful pointer to what may be expected from those power stations.

2. SOURCES OF RADIOACTIVE WASTES

From a reactor station such as Chapelcross small quantities of radioactive effluent are discharged to the environment in two ways. The main radiation absorbing, or biological shield, of the reactor is cooled by blowing air past it. This air is drawn in near ground level and is ejected from two 250-ft stacks, one on each side of each reactor. The air passes through a region inside the biological shield where there are substantial neutron fluxes and a certain amount of in-
duced activity is produced in the air. This is principally the short-lived isotope argon-41. During blow-down procedures there exists the possibility of release of fission products which have escaped from faulty fuel elements into the coolant gas. It will be clear that in these circumstances precise control of discharges before release is not practical.

The second source of low-level radioactivity is the cooling ponds where the fuel elements are stored after removal from a reactor and before transportation to the processing plant. In the course of operation of these ponds, a small quantity of radioactivity gets into the cooling pond water as a result of the corrosion of the canning material of the uranium elements in which some activity has been induced, or by leakage from the uranium to the water through the canning material, or occasionally because damaged elements are in the water. The capacity of each of the two cartridge cooling ponds is 400,000 gal of water and some 6% of the volume of the pond is discharged to the Solway Firth each day. Water to be discharged is transferred from the ponds to a detention tank where it is held until discharge time, which is between high tide and high tide plus two hours. While in the detention tank the water is sampled and measured for activity before discharge is permitted. Discharge of liquid and gaseous effluent is carried out under authorizations granted by the Secretary of State for Scotland. The authorized discharge for liquid effluent, in a period at high tide as stated above, is up to 22.5 Ci every three months of total alpha-plus-beta activity, this activity to contain no more than 112.5 mCi of strontium-90. Records of the quantity of radioactive liquid effluent discharged are supplied regularly to the Scottish Development Department. In contrast to the gaseous effluent situation, primary control on liquid effluent is exercised by monitoring the waste before disposal, and district survey becomes a second line of defence.

3. ENVIRONMENTAL MONITORING PROGRAMME

In achieving the primary aim of routine environment surveys, which is to show that the public health is not endangered, the material collected and analyses performed should make it possible to estimate the radiation dose to persons or, occasionally, to animals of economic importance resulting from the release of radioactive materials from the reactor site during normal operations. The conduct of routine
surveys thus presupposes the release of radioactive wastes, for in practice it is impossible to operate a reactor station which discharges no radioactivity in its wastes.

The principal potential hazard to members of the public from radioactive materials released into the environment arises from the ingestion of contaminated food or water, and the accumulation of data has revealed that, in the circumstances pertaining to Chapelcross, the item of human diet which could convey the largest amount of radioactivity into the human body is milk. Accordingly, monitoring cover in relation to gaseous effluent is provided by milk sampling, the samples being analysed for $^{131}$I and $^{90}$Sr and $^{90}$Sr, which are the most important components of the fission-product mixture, and for all of which milk is the predominant source in the human diet in United Kingdom conditions.

Milk sampling is undertaken from twelve farms in two groups, one group being within a radius of three miles of the site and the other between three and five miles from the station. The maximum radius of five miles has been selected because this is the distance up to which, in adverse meteorological conditions, following the maximum credible accident to a reactor, milk might be contaminated at a level which is unfit for human consumption. Thus routine sampling carried out up to such a radius means that a comfortable margin of cover is provided for any incident up to a maximum credible one. Milk is a most convenient material since samples are obtained without difficulty, and since cows graze over a wide area a herd sample may be regarded as representing truly the conditions pertaining in the locality.

The results for the measurements of $^{131}$I in milk since the start of operation of the station and similar figures for $^{90}$Sr in milk are shown in Figs. 1 and 2. The minimum level of activity of $^{131}$I which can be measured is 20 pCi/litre and this level is only exceeded, as will be seen, on occasions when there is significant fallout following weapon testing. Although delayed somewhat in time by the retention of a fallout material in the upper atmosphere a similar pattern can be seen in the $^{90}$Sr figures. The maximum permissible concentration of $^{131}$I in milk for populations around a nuclear energy establishment as specified by the British Medical Research Council, is 600 pCi/litre. The corresponding figure for $^{90}$Sr is 400 pCi/g of dietary calcium.

It should be noted that in this relatively mild part of the United Kingdom cattle are usually in the fields all year round. However, during winter months supplementary feeding by such materials as
kale and oil cake is required and comparatively high levels of activity on the grass therefore may not be reflected to such a marked degree in the activity in milk. This fact underlines the importance of measuring in surveys a quantity which can be directly related to an effect on the human and it may be necessary, for example, when cattle are housed during the winter, to attempt to predict, from measurements made on grass, the levels in milk that will be found when the animals are turned out to pasture.

Liquid effluent, as stated previously, is discharged to the Solway Firth. Here the sampling programme is more varied and includes sand, seaweed, seabed sludge, shrimps, flounders and salmon. Sand sampling is carried out to ensure that no external radiation hazard to people using the beaches will result and sea-bed sludge is collected since it may contaminate fishing nets which are subsequently handled. This is the only possible external hazard and most other measurements are concerned with contamination of human food. Seaweed is looked at because of its potential use in making lavar bread although
the variety used for this is practically non-existent in the Solway region. A large part of the United Kingdom market for shrimps is supplied from the Solway area and salmon fishing is an important industry. In the grounds fished, shrimps are only available between spring and late autumn, after which they move out into the deeper and warmer sea.

Collection of all these samples is on a six-weekly cycle except for shrimps which are collected every four weeks in the season. Sand is collected from fifteen different locations and seaweed from four. For all these materials gross beta activity is measured while in the case of shrimps, flounders and salmon, analysis is carried out for strontium-90, the most potentially hazardous of the material released in the liquid effluent. Discussion of the Solway Firth sampling programme with the Government bodies concerned is pending and it is possible that some reduction in the range of materials sampled and in the measurements made will result which will place the emphasis of the work more clearly on the route back to man which is of greatest potential hazard.
The values obtained from the above surveys can be related to so-called derived working limits (D. W. L.). These are obtained as follows. From a study of the fishing and of the eating habits of the population it can be found that the maximum daily consumption of fish in certain specified circumstances is about 25 g/d near the outlet from a nuclear establishment. The I. C. R. P recommendations for drinking water imply a mean daily intake of radioactivity by an individual member of the public of \( \text{MPC}_w \times 2200 / 10 \ \mu\text{Ci/d} \). If this is divided by the consumption figure of 25 g/d for fish, one obtains a derived working limit of \( \text{MPC}_w \times 10 \ \mu\text{Ci/g} \). This will lead, for example, to a derived working limit of 10 pCi/g for \(^{90}\text{Sr}\) in the edible parts of fish.

4. PRE-EMERGENCY SURVEYS

A major reactor accident must be expected to release a substantial quantity of fission products to the air and possibly also to local surface waters. The primary function of an emergency survey will be to establish what control measures are necessary and over what area they have to be applied. The secondary objective will be to establish as detailed as practical a picture of the contamination of the environment since this will be of value in assessing the validity of claims for damage and in drawing scientific conclusions about the accident and the behaviour of the released materials.

The emergency survey will consist primarily of a very large number of specific analyses of critical materials, notably milk but also possibly eggs and vegetables. The results obtained must be capable of realistic interpretation, and gross beta measurements are almost completely inappropriate in emergency surveys. However, one type of non-specific measurement may be of value if there is sufficient knowledge of the composition of the escaping radioactivity. This is the measurement of gamma radiation from the ground. Preparations for such measurements have been made at Chapelcross and although not required as a routine measurement, in order to keep staff suitably trained in the use of equipment and familiar with the locations, measurements of gamma-ray levels at 1 m above the ground are made at 36 points around the site at a radius up to five miles. The results of such a survey are shown in Fig. 3, where the effects of fallout in periods clearly following weapon tests, can be seen. The isotope which again is most relevant to a hazard in the
circumstances pertaining at Chapelcross is $^{131}$I and it should be noted that the increase in $\gamma$-ray dose-rate measured, due to a concentration of $^{131}$I in the ground which would yield the emergency concentration in milk, is very small, so that a knowledge of the $\gamma$-ray value before the deposition is necessary. If the composition of the escaping radioactivity is unknown, or is in doubt, such $\gamma$-ray measurements will have to be supplemented by more detailed analyses and adequate chemical and physical facilities must be available to carry out analysis for specific isotopes on the many samples collected. The isotope which again is most relevant to a hazardous situation in the circumstances pertaining at Chapelcross is iodine-131.

Finally, it should be stated that it is necessary to carry out pre-operational surveys of the $\gamma$-ray background and for $^{90}$Sr in milk.

The former is necessary since the increase in $\gamma$-ray dose-rate measured because of a concentration of $^{131}$I in the ground, which would yield the emergency permissible concentration in milk, is very small.

The $^{90}$Sr survey should be started before the plant operates because the area concerned may be typical in the behaviour of strontium in fallout. Once its relationship to, for example, the national pattern has been established, routine results can be interpreted with the aid of the results from the surveys carried out over the whole country.

Table I shows typical plans for district survey programmes as carried out at Chapelcross, while Fig. 4 shows the geographical location of the station together with sampling points for the various surveys.
<table>
<thead>
<tr>
<th>Day</th>
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<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
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<td>1/4-5/4</td>
<td>Milk collection</td>
<td></td>
<td></td>
<td>Salmon</td>
<td>Holiday</td>
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<td></td>
<td>(special outer)</td>
<td></td>
<td></td>
<td>Holiday</td>
<td></td>
</tr>
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<td>Seabed and seawater</td>
<td>Gamma survey 0-4 mls</td>
<td>Gamma survey 4-9 mls</td>
<td>Gamma survey 9-15 mls</td>
<td>Seashore survey L.T. 09.37</td>
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<td></td>
<td>H.T. 10.53</td>
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<td></td>
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<td></td>
<td>Radiation survey L.T. 08.34</td>
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<td></td>
<td></td>
<td></td>
<td>Radiation survey L.T. 13.58</td>
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<td></td>
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<td>--------</td>
</tr>
<tr>
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<td>Seabed and seawater H.T. 11.26</td>
<td>Gamma survey 4-9 mls</td>
<td>Salmon</td>
<td>Seashore survey L.T. 08.31</td>
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<tr>
<td>3/6-7/6</td>
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<td>Milk collection (special inner)</td>
<td>Pipeline and site survey</td>
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<td>Gamma survey 9-15 mls</td>
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<tr>
<td>24/6-28/6</td>
<td>Seabed and seawater H.T. 15.14</td>
<td></td>
<td>Radiation survey L.T. 11.54</td>
<td>Rainwater collection</td>
<td></td>
</tr>
</tbody>
</table>

L.T. = Low tide  H.T. = High tide
* U.K.A.E.A.-P.G., Chapelcross Works Health Physics and Safety Department

This publication is not longer valid
Please see http://www-ns.iaea.org/standards/
FIG. 4. Geographical location of Chapelcross showing sampling points for various surveys
1. INTRODUCTION

The safe handling of liquid radioactive wastes arising from individual users of radioisotopes in Czechoslovakia is very complicated and thorough. For this reason a central organization, which is responsible for the collection, control, and long-term storage of these wastes, was established some years ago. This organization also provides for the central distribution of radioisotopes and lists all items of the sold radioisotopes, an important factor in the movement of radioisotopes. This paper briefly reviews the experience in operating the central radioactive wastes-storage facility, and the procedures of environment monitoring control and equipment.

2. DESCRIPTION OF THE FACILITY FOR THE LONG-TERM STORAGE OF RADIOACTIVE WASTES

(a) Short technological description of radioactive waste management for long-term storage

When selecting the site for the long-term storage of radioactive wastes we have mainly considered the hygienic, safety and economic questions. A special concrete building above the ground is not only disadvantageous from the hygienic point of view but is also too expensive; further, it is impossible to avoid the contamination of ground water. The surface trenches, whose sides are made from concrete, often coated with an asphalt layer to prevent the infiltration of ground and
rain water, are less expensive, but should be placed far from working and living areas where there is a deep level of ground water and the ground soil layers have a high adsorption capacity. The storage in natural underground caverns still calls for careful geological and hydrological studies, which are necessary to ensure that full consideration is given to prevent the contamination of water supplies. Man-made caverns in natural formations, including abandoned mineshafts, usually have water-drainage problems and, because of a danger of contaminating ground water, are not suitable. Through geological and hydrological studies it has been proved that in Czechoslovakia, as far as safety and economy is concerned, the abandoned galleries above the ground-water horizons, surrounded by sufficiently thick and water-tight soil layers, are the most convenient ones. This storage facility has the most suitable geological conditions, and sufficient storage capacity, and when proper packaging is used the leakage of radioactivity to the environment is reduced to a minimum.

In the galleries it is necessary to store the radioactive wastes in a form that would prevent the contamination of the designed spaces. For this reason the radioactive wastes are first of all concentrated in small volumes and deposited in metal drums, which then are shipped to the central storage facility. Here the wastes are stored until the radioactivity decreases to a treatable level. Before packing in the laboratories it is essential to segregate radioactive wastes into two or more groups according to the half-lives of the radioisotopes involved. Wastes with short-lived radioisotopes - shorter than 20 days - are allowed to decay in the laboratory building, while the long-lived radioactive wastes are transported to the long-term storage facility. There they are deposited separately according to their origin and divided into three groups:

1. Liquid radioactive wastes and sludges incorporated in concrete or asphalt;
2. Biological radioactive wastes fixed with formaline and loaded with chlorlile;
3. Solid wastes.

Radioactive wastes are transferred to the central long-term storage facility in closed metal drums, the surfaces of which are decontaminated. The intensity of the dose should not exceed 50 mr/h. Each drum must be accompanied by a certificate stating the kind of waste, the radioisotopes contained, the level of activity, surface dose, result of abrasion test etc. The transportation of radioactive wastes is done by special motor trucks equipped with a hydraulic
crane. The drums are transferred from the truck onto a platform-lorry and then taken to the storage place where they are piled up in three or four layers by a lift-truck, driven with a combustion-type engine.

People working with low active wastes in the storage facility usually wear protective clothing, for instance, special shoes or overshoes, gloves, etc. such as those worn in active laboratories. In the event of an accident three protective suits are available for the service staff to protect them against the absorption of radioactive particles through the skin or sensory organs. The protective suit is connected to the pressure air line.

(b) Location

For the long-term storage of solid radioactive wastes in Czechoslovakia we selected abandoned limestone galleries, located far from water streams and settlements. For storage facility a small part of the horizontal galleries is reserved, segregated from the main gallery by a metal gate (see plan in Fig. 1).

The external space, designed for long-term storage, is surrounded by barbed wire. Entrance is allowed only through the watch-house, in which are located the sanitary loop, hygienic rooms, area for decontaminating the trucks, air-pressure compressor, diesel-electric machinery, main switch, etc. The long-term storage facility is located in the Czech chalk massif, which consists of limestone and fine sandstone rocks, clay and lime marl limestone and clayey sandstone. The horizontal layers are connected with one another by the gradual penetration of one grade into another. The surface layer of the mine consists of almost waterproof clayey rocks below which are layers of clay and lime marl.

The bottom layers consist of lime marl below which are marl sandstones. The hydrogeological conditions are influenced by the permeability of the cover rocks which consist mainly of clayey earth, which prevents the infiltration of rainwater and the formation of a continuous ground-water table near the land surface. This soil also prevents the infiltration of rain and surface water into the rock-bed. Ground water was found quite deep down in the sandstone marl with a slight permeability. The surface topograph above the long-term storage facility is located in an area of low population density, with frequent winds and relatively low atmospheric rainfalls.
The inside galleries are self-supporting. Lime marl is a self-bearing rock, resisting disintegration, and when the surface is coated...
with a rubber base, it is well protected for a long time against any disintegration. The bottom and lower part of the gallery walls, which consist of lime marl, have to be reinforced with a concrete layer. For safety reasons the galleries are braced with a reinforced concrete support construction and a steel wire net.

3. SOURCES OF DISCHARGED RADIOACTIVE MATERIALS

When the radioactive waste is to be stored for an unlimited period care must be taken to prevent radioactivity escaping and spreading to the environment. For this reason control of the activity in the ground water in the environment is required. Water samples from control pits and from exploratory borings made during geological studies are used for this purpose. The measurement of the activity of the environment had proved that the activity in the storage spaces is practically the same as those values which had been measured before setting up the storage facility. The purity of the atmosphere has been verified by the results of abrasion tests from the floor and the walls.

Water contamination of the surrounding areas was the main concern. The condensation of water vapours on the walls occurred during the summer. However, the amount of condensate was very small, but it has an unfavourable effect by corroding the containers. Several years of operation in the storage facility has shown that no infiltration of rain water into the mine occurred. The control pits in the gallery and those at the entrance were practically dry. Also, the radioactivity levels of ground waters from control borings were not higher than those in the natural background.

4. ENVIRONMENTAL MONITORING PROGRAMME

Dosimetrical control of long-term storage facility is carried out once a month and the results of the measurement are entered in the control book. The control includes:

(a) Doses in different parts of the corridor;
(b) Doses in different parts of the inlet corridor and the main surroundings;
(c) Activity of aerosols in the air of the storage hall;
(d) Activity of water in the control pit;
(e) Activity of water in the surroundings of the storage facility;
(f) Activity of ground water.

5: ROUTINE SURVEYS

(a) Radiation intensity control is carried out by means of current intensimeters (for instance, METRA-N-10 or METRA-N-20) and a special intensimeter, TESLA-NIC. The instruments consist of G-M tubes, amplifier, integration circuit and a pointer indicator of radiation intensity. It is also possible to use the instrument DIMETR with an ionization chamber, also the instrument NQU with a battery supply. This also consists of G-M tubes for alpha, beta, and gamma radiation, and a portable integrator unit.

When the radiation background is high, a control of the surface contamination is carried out by means of an abrasion test. This procedure is needed especially for the control of contamination in metal containers in which radioactive wastes are conveyed. The abrasion test is carried out in the following way: from a surface area of 150 cm$^2$ the contamination sample is taken by lengthwise rubbing by the use of a piece of filter paper (3.5 cm x 3.5 cm in size), and then measuring with an instrument. This abrasion test is taken on the surface of each container.

(b) Liquids

The liquid samples are taken from control pits and exploratory borings and placed into 100-ml polyethylene bottles. The measurement is carried out by means of the tubes for beta; and gamma liquid measurements are done by an integrator. The maximum sensitivity of these tubes is $10^{-8}$ Ci/l for energies corresponding to $^{90}$Y. To gain higher sensitivity ($10^{-12}$ Ci/l) the anticoincidental connection of the G-M tube and the scintillation detector is used, and this is also used to measure the solid residue after evaporation. For the activity measurement of soft beta-emitting radionuclides a scintillator with a sensitivity of about $10^{-7}$ Ci/l is applied. $^{226}$Ra is measured by means of the emanometric method with a sensitivity of $10^{-11}$ Ci/l.
(c) **Air**

Air samples are sucked into evacuated ionization chambers with a volume of 750 ml and the ionization current is measured with a Zeiss Jena electrometer SG-1M. This method is used especially for $^{222}$Rn. Other isotopes are measured by the electro-precipitation method with electrostatic precipitators from Friseke-Hoepfner of Lenger-Kovařík (6–10 kV, precipitation time 4–30 min, passage 1–150 l/min of air). The present aerosols are precipitated on the filtration paper or aluminium foil by means of corona discharge between sparkling electrodes. The measurement is carried out by G-M tubes, or a TESLA integrator, or a Friseke-Hoepfner $4\pi$ counter.

6. **SPECIAL ROUTINE SURVEYS**

(a) **Solids**

Should the storage hall or inlet corridor become contaminated, an abrasion test sample is taken from the surface to identify the type of isotope and then which container is the source of contamination. Analyses are carried out by means of high-voltage electrophoresis in citrate medium, or by spectral dosimetric analyses.

(b) **Liquids**

Differentiations of contained radioisotopes in liquid wastes or ground water are carried out by high-voltage electrophoresis, spectral dosimetric analyses with a spectrometric analyser with TESLA impulses, or absorption analyses by means of aluminium foils for crude differentiations of beta emitters on the basis of their different energies.

(c) **Air**

The same methods as mentioned above are used for analysing aerosols from air which are removed by electroprecipitators on filter papers.

7. **EVALUATION OF THE RESULTS** (see Table I)
### TABLE 1

#### EVALUATION OF THE RESULTS

Results of most recent tests made

<table>
<thead>
<tr>
<th></th>
<th>Instrument</th>
<th>Measured doses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Doses in different parts of corridor</td>
<td>METRA N-20</td>
</tr>
<tr>
<td>2.</td>
<td>Control of inlet corridor and main surrounding contaminations</td>
<td>alpha, beta, gamma contamination NQU</td>
</tr>
<tr>
<td>3.</td>
<td>Concentration of $^{222}$Rn</td>
<td>ionization chamber SG-1M</td>
</tr>
<tr>
<td>4.</td>
<td>Surface decontamination by means of abrasion test</td>
<td>F-H-4 counter</td>
</tr>
<tr>
<td>5.</td>
<td>Activity of water in control pit</td>
<td>liquid tube</td>
</tr>
<tr>
<td>6.</td>
<td>Activity of water in the storage-facility surroundings</td>
<td>liquid tube</td>
</tr>
<tr>
<td>7.</td>
<td>Activity of ground water</td>
<td>anticoincidence equipment</td>
</tr>
</tbody>
</table>
ANNEX V

ENVIRONMENTAL MONITORING AROUND A URANIUM MILL IN THE UNITED STATES OF AMERICA

E. C. TSIVOGLOU
PHYSICAL AND ENGINEERING SCIENCES UNIT
ROBERT A. TAFT SANITARY ENGINEERING CENTRE
OHIO

1. INTRODUCTION

The environmental monitoring system described here illustrates the combined effects upon a river environment of waste-disposal operations from an operating uranium mill, and the residual effects from an abandoned uranium mill located approximately 15 miles upstream.

PLANT DESCRIPTION

This particular operating uranium mill utilizes the acid leach-solvent extraction process for the recovery of uranium. Vanadium is also recovered by ammonia precipitation. The recovery of uranium is carried out by leaching uranium from finely ground ore with sulphuric acid, subsequent extraction of uranium from leach liquors by means of an organic solvent, and precipitation of the uranium as the oxide (U₃O₈). Vanadium is not completely recovered but is precipitated as ferric vanadate and trucked to another company mill for complete vanadium recovery.

The area described is located in the south-western United States of America in the State of Colorado. The climate of the area is semi-arid with a total annual rainfall averaging about ten inches. The river that flows past the mill is a typical mountain stream, relatively shallow and swift. It originates in high mountain terrain and the area around the mill generally consists of narrow canyons and small valleys. There are extended periods of low flow in the neighbourhood
of 25 ft³/s (generally October through March) in the river, with periods of flood flow of as much as 1000 ft³/s from snow melt during the late spring. Summer flows are usually low with brief periods of high flow occurring in the early autumn because of intermittent rainfall. At a distance of about 5 miles below the mill the river joins a larger stream, which in turn enters the Colorado River after flowing about 70 miles. Figure 1 shows the area in the vicinity of the mill and the river monitoring stations. Some 1000-1500 persons (most of whom are mill or mine employees) live in the area.

FIG. 1. Environmental monitoring area - uranium mill vicinity

2. SOURCE OF RADIOACTIVE WASTES

The waste sources at the mill include the following three main types: (1) Barren acid liquors which have been stripped of uranium and vanadium values. These liquors are treated with barium salts for the precipitation of dissolved radium. They account for about 50% of the volume of the total mill discharge. Originally these
wastes were discharged to the river after passing through small holding ponds. At present they are being piped to large evaporation and seepage ponds. These wastes are highly acidic in nature and contain relatively large amounts of dissolved thorium; (2) Stripped ion-exchange eluate, or "yellow cake tails". These wastes are at a near-neutral pH and are discharged to the river after passing through small holding ponds located adjacent to the river; (3) Vanadium precipitation liquors, or "red cake tails". These were originally discharged directly to the river but at present, since vanadium is not completely recovered, little if any wastes originate from this source.

Spent ore solids (tailings) from the acid-leach process are slurried and discharged to large tailings ponds located some distance from the river. Essentially all the pond liquid is recycled to the mill process. However, small seeps occur from the tailings pond and eventually reach the river.

In addition to the above-mentioned wastes, several other small waste streams (primarily cooling water) are discharged to the river. Very little airborne wastes occur at United States uranium mills and there are generally no environmental monitoring programmes conducted in the area surrounding the mill. Waste gases from furnaces and other mill activities are usually scrubbed for particulate removal before release to the atmosphere. Airborne contamination is generally limited to areas within the interior of the plant proper.

3. ENVIRONMENTAL MONITORING PROGRAMME

The monitoring programme described for this uranium mill is a part of a much larger monitoring programme currently being carried out by the United States Public Health Service throughout the entire Colorado River Basin. The over-all programme includes a radium monitoring network of 26 stations, including both continuous automatic sampling of river water as well as routine grab sampling. Such a network was established to provide continuing surveillance of the effects of uranium-mill waste discharges upon the waters of the Colorado River Basin.

Figure 1 shows the particular monitoring area considered in this paper. In addition to the water monitoring stations shown in Fig. 1, special short-term sampling of river sediment material has been carried out periodically. At other times short intensive surveys of mill effluents and of the chemical and biological effects of mill ef-
fluents upon the water environment have been carried out. For purposes of this discussion only the data obtained from the water-monitoring stations and the sediment data are presented.

Water samples have been analysed primarily for dissolved $^{226}$Ra and uranium, although limited isotopic analyses ($^{210}$Pb, Th, Po) have been carried out on a few of the samples. River sediment material has been analysed mainly for $^{226}$Ra and gross alpha radioactivity, but other isotopic analyses have also been performed on these materials. $^{226}$Ra analyses have been performed by the classical radon emanation technique as described by Rushing [1]. Uranium analyses have been by fluorometric procedures, while gross alpha determinations have been carried out by gas-flow internal proportional-counting techniques.

4. PRESENTATION OF DATA

Table I presents a description of the three radium monitoring network stations shown in Fig. 1. The automatic pump-timers are so designed that an equal volume of river water is collected once every 15 min and discharged to a polyethylene collection vessel. These vessels are removed weekly and the contents are either analysed as weekly samples, or the weekly samples are composited into a monthly sample for analysis. As indicated in Table I, the samples from all three stations were initially analysed as weekly composites. At present only the samples from Station C continue to be analysed as weekly composites, while samples from Stations A and B are analysed as monthly composites.

Table II presents a summary of dissolved radium and uranium concentrations at the three monitoring stations from October 1961 through December 1963.

Table III presents a summary of data on sediment samples collected at the water-sampling station locations.

5. DISCUSSION OF DATA

It can be seen from Table II that a definite pattern exists in regard to the radium and uranium concentrations proceeding downstream from Station A to Station C. At Station A the concentrations found are natural background concentrations comparable to other background locations throughout the Colorado River Basin.
TABLE I
DESCRIPTION OF MONITORING STATIONS

Station A:
Established: 28 October 1961
Type: Automatic pump-timer
Analyses: $^{226}$Ra and uranium
Data: Reported as weekly averages 28/10/61 - 1/4/62
Reported as monthly averages 1/4/62 - Present

Station B:
Established: 27 October 1961
Type: Automatic pump-timer
Analyses: $^{226}$Ra and uranium
Data: Reported as weekly averages 27/10/61 - 1/4/62
Reported as monthly averages 1/4/62 - Present

Station C:
Established: 9 October 1961
Type: Automatic pump-timer
Analyses: $^{226}$Ra and uranium
Data: Reported as weekly averages 9/10/61 - Present

The data for Station B show a definite five-fold increase in concentrations of $^{226}$Ra and uranium and are the result of residual contamination from waste tailings at the abandoned uranium mill. These tailings are located on the banks of the river, and seasonal high river flows combined with heavy rainfall flush some of the tailings into the river channel, after which some of the radioactivity content of these solids becomes dissolved in the river water by a leaching process.

At Station C it can be seen that the effluents discharged to the river by the operating uranium mill result in a further increase of radium and uranium concentrations by a factor of about 4 over those found at Station B.

Sediment data given in Table III show that the same patterns of increase exist as described above. These data are limited, but the effects are evident.

The above brief discussion illustrates the effect of uranium milling activity upon a short river stretch, and describes a monitor-
### TABLE II

**RIVER-WATER RADIOACTIVITY CONCENTRATIONS**

<table>
<thead>
<tr>
<th></th>
<th>Dissolved $^{226}\text{Ra}$ (pg/l)</th>
<th>Dissolved uranium ($\mu$g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Station A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.04</td>
<td>1.3</td>
</tr>
<tr>
<td>Range</td>
<td>0.0-0.09</td>
<td>0.0-3.9</td>
</tr>
<tr>
<td>Number of samples</td>
<td>43</td>
<td>15</td>
</tr>
<tr>
<td><strong>Station B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.25</td>
<td>7.8</td>
</tr>
<tr>
<td>Range</td>
<td>0.05-1.3</td>
<td>0.9-63</td>
</tr>
<tr>
<td>Number of samples</td>
<td>76</td>
<td>45</td>
</tr>
<tr>
<td><strong>Station C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1.1</td>
<td>26</td>
</tr>
<tr>
<td>Range</td>
<td>0.11-5.6</td>
<td>0.0-150</td>
</tr>
<tr>
<td>Number of samples</td>
<td>94</td>
<td>65</td>
</tr>
</tbody>
</table>

Aning programme designed to evaluate continuously these water-quality effects. The example was chosen in order to present a clear picture of one type of monitoring programme. This particular programme is not applicable to the entire Colorado River Basin because various water uses such as irrigation, industrial or municipal water supply, or recreation, may dictate the additional sampling of crops, farm topsoil, filter sands, fish, etc., to demonstrate more fully the total effects of uranium-milling activity in a particular situation.

Some brief mention should be made of the comparison of the data given in Table II with the United States Public Health Service Drinking Water Standard for $^{226}\text{Ra}$ of 3.0 pg/l. The average radium concen-
TABLE III

SEDIMENT RADIOACTIVITY CONCENTRATIONS

<table>
<thead>
<tr>
<th></th>
<th>$^{226}{\text{Ra}}$ (pCi/g)</th>
<th>Gross alpha (pCi/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Station A</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>0.93</td>
<td>8</td>
</tr>
<tr>
<td>Range</td>
<td>0.9-1.0</td>
<td>6-10</td>
</tr>
<tr>
<td>Number of samples</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td><strong>Station B</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>4.5</td>
<td>24</td>
</tr>
<tr>
<td>Range</td>
<td>2.0-8.7</td>
<td>15-33</td>
</tr>
<tr>
<td>Number of samples</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td><strong>Station C</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>8.5</td>
<td>59</td>
</tr>
<tr>
<td>Range</td>
<td>6.0-11</td>
<td>38-95</td>
</tr>
<tr>
<td>Number of samples</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

tration from Station C is seen to be 1.1 pg/l or one-third of the drinking water limit. This is the highest average $^{226}{\text{Ra}}$ concentration at present being found in the entire Colorado River Basin.

Such low dissolved $^{226}{\text{Ra}}$ concentrations have not always been the case in streams of the Colorado Basin. In contrast to the data presented above, river-water samples collected from the same river in the vicinity of Station C in 1950, 1955, 1956 showed dissolved $^{226}{\text{Ra}}$ concentrations as high as 86 pg/l. During this mid-1950 period at Station B, when the mill above this station was in operation, river-water samples showed dissolved radium concentrations as high as 22 pg/l. Stream sediments collected in 1956 from locations close to Stations B and C showed radium concentrations as high as 730 pg/g.
Water and sediments collected near Station A during this period showed radium concentrations essentially the same as the values given in Table III. The great degree of improvement of river-water quality since the mid-1950's has resulted from the co-operative efforts of the industry, the United States Atomic Energy Commission, and the United States Public Health Service, and demonstrates the high degree of water-quality protection that can be achieved by reasonable measures.

In summary, a simple monitoring programme such as has been described for a particular locality can yield very worthwhile information concerning the effects of uranium-mill effluents upon the water environment, and can be designed and conducted with considerable flexibility depending upon particular needs.
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FIGURES FOR ANNEX I

ENVIRONMENTAL MONITORING IN THE AREA OF THE CADARACHE NUCLEAR STUDIES CENTRE
FIG. 1. Location of the Cadarache site

Results and measurements are given in µR/h

○ Intermittent measurements (mobile stations)
△ Continuous measurements (fixed stations)

FIG. 3. Gamma radioactivity