RECOMMENDATIONS

Monitoring of Airborne and Liquid Radioactive Releases from Nuclear Facilities to the Environment
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MONITORING OF AIRBORNE
AND LIQUID RADIOACTIVE RELEASES
FROM NUCLEAR FACILITIES
TO THE ENVIRONMENT
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FOREWORD

Authorized upper limits are prescribed for the activities of radioactive materials that can be released to the environment in airborne or liquid form during the normal operation of a nuclear facility. The purpose of setting such limits is to ensure continuing compliance with the dose limitation system recommended by the International Commission on Radiological Protection for members of the general public.

The monitoring of these releases is an important part of the verification system by which the operator of the facility can provide assurance to himself, to the national regulatory authority, and to the public that the actual releases to the environment under normal operating conditions do not exceed the authorized limits. It can also provide early warning, and an indication of the nature and extent, of any abnormal release resulting from an accident in the facility or a failure of the release control systems.

The aim of this manual is to define the objectives of effluent monitoring programmes, and to provide guidance on the design of adequate systems and on the choice of appropriate monitoring methods and instruments for different types of nuclear fuel cycle facilities. It was prepared by an Advisory Group under the Chairmanship of Dr. J. Schwibach (Federal Republic of Germany) which met from 9 to 13 September 1975.

Examples of the methods and equipment used for measuring radioactive airborne and liquid releases and of comprehensive monitoring programmes and requirements, provided by members of the Advisory Group, are included in the manual as annexes to the main text.
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1. INTRODUCTION

1.01. The recommendations of the International Commission on Radiological Protection (ICRP) [1], relating to radiation protection of the public, include the following general statement: "The authority in charge of any establishment or operation which might cause environmental contamination should limit the exposure of members of the public so as to comply with relevant national or local requirements, and with the Commission's recommendations, by controlling the release of radioactive material into the environment."

1.02. The national or local requirements referred to in this statement usually take the form of authorized limits on the releases of radioactivity in airborne and liquid effluents to the environment from facilities and operations in which radioactive materials are used. A document of the International Atomic Energy Agency [2] describes how such limits may be established. Examples of specific regulatory requirements and guides are given in the bibliography to this manual.

1.03. It is the responsibility of the authority in charge of the facility or operation (usually referred to as the operator) to provide assurance that the actual releases during normal operation do not exceed the authorized limits, and to notify the appropriate authorities and initiate any prescribed actions in the event of an unplanned release exceeding the authorized limits.

1.04. The principal means of providing such assurance is the operation of a system for monitoring airborne and liquid effluents from the facility to show that the amount of radioactivity released is within the authorized limits or, in the event of unplanned releases, to ensure that early warning is given so that, if necessary, appropriate protective action can be initiated.

1.05. The aim of this manual is to define the objectives of effluent monitoring programmes for planned and unplanned airborne and liquid releases of radioactive materials to the environment and to provide guidance on the design and operation of adequate monitoring systems for different types of facilities.

1.06. Attention will also be given to the keeping of records of measurement results in a manner that facilitates comparison with the authorized limits and with the releases from other facilities, and to the periodic reporting of the results in a uniform manner.

1.07. It is not intended to include any consideration of the design of the complementary environmental monitoring programmes. Information on this topic is available in another issue of the Safety Series [3].

1.08. It is hoped that the guidance provided will be of help to the operators of nuclear facilities, particularly in countries which are in the process of establishing systems for controlling the release of radioactive contaminants to the environment.
2. OBJECTIVES OF EFFLUENT MONITORING

2.01. The authority in charge (usually referred to as the operator) of any establishment or operation which has a potential for releasing radiologically important amounts\(^1\) of radioactive materials to the environment has an obligation to limit the exposure of members of the public and must therefore control the release of radioactive material into the environment and demonstrate that it is within the authorized discharge limits. In addition, the operator will usually establish his own operating limits on effluents for purposes of his administrative control or to verify that effluent treatment and control systems are functioning in accordance with design specifications. It is the responsibility of the operator to ensure that under normal operating conditions the releases from the facility conform with the authorized limits and other conditions of the authorization as well as with any other self-imposed operating limits, and also to ensure that early warning is given of the nature and extent of any unplanned releases.

2.02. Effluent monitoring systems are intended to measure radioactivity in airborne and liquid effluents before discharge to the environment. Environmental monitoring systems are intended to measure levels of radioactive contaminants in selected environmental media. The two systems are complementary. Except in those cases where reconcentration of radioactivity occurs in specific environmental media, the activity concentration is normally higher in the effluent stream before dilution in the environment, and the radionuclide mixtures or individual radionuclides can be identified and measured there with greater accuracy for comparison with the authorized discharge limits.

On the other hand, environmental monitoring provides a more direct assessment of the levels of radioactive contaminants to which members of the public are exposed. In addition, environmental monitoring may be carried out to provide assurance to the public and to determine whether releases other than those detected by the effluent monitoring system have occurred or are taking place. Effluent monitoring is always required if radiologically important amounts of

\(^1\) Radiologically important amounts of radioactive materials comprise radioactivity levels which are of interest from the point of view of protection of the public and the environment. It is possible to specify such levels of radioactivity in terms of a stated fraction of the applicable standards or authorized limits (e.g. 10% of the ICRP values for MPC\(_a\) or MPC\(_w\)); however, the determination of the concentration or quantity of radioactivity that is truly ‘radiologically important’ is variable, frequently subjective, and depends on such things as the nature of the operation in question, the particular nuclides involved, and the dictates of national and local interests.
radioactive contaminants are being released from a facility or if there is a potential for radiologically important unplanned releases; environmental monitoring may also be required if the potential releases of radioactivity could result in a significant fraction of the dose limits to critical groups or to the whole population. Information on the objectives and design of environmental monitoring programmes is given in the IAEA Safety Series No.41 [3].

2.03. The primary objectives of effluent monitoring are the following:

(a) To demonstrate compliance with the authorized limits on releases of airborne and liquid radioactive contaminants to the environment and with self-imposed operating limits.
(b) To provide data and information which, with pertinent environmental models, will permit an estimation of population exposure to radiation caused by effluent releases.
(c) To indicate whether, and to what extent, supplementary environmental measurements or programmes of environmental monitoring are required.
(d) To provide information to demonstrate that plant operation and effluent treatment and control systems are performing as planned.
(e) To assure the public that releases are being properly controlled.
(f) To rapidly detect and identify the nature and extent of any unplanned releases to the environment.
(g) To activate any warning or emergency response systems that may be required.
(h) To provide information for the rapid assessment of possible hazards to the public from inhalation, ingestion or exposure to external radiation as a basis for initiating protective actions or special environmental surveys.

These objectives are not listed in order of priority since the priorities will vary depending on the circumstances that prevail at any given site. Their relative importance will also vary with the nature and amount of radionuclides that could potentially be released.

2.04. Additional information that can be obtained from effluent monitoring, possibly in conjunction with environmental monitoring, includes:

(a) Information that leads to a better knowledge of the behaviour of the effluents and the dispersal of radioactive material in different sectors of the environment.
(b) Information for quality control and intercomparison of monitoring systems, methods and results.
(c) Information on the relationship between the type of operation performed and the levels of radioactivity released.
3. EFFLUENT MONITORING PROGRAMMES

INTRODUCTION

3.01. The essential requirement for any monitoring programme for radioactive effluents is that it should fulfil the primary objectives defined in para. 2.03. The desirability of obtaining the additional information listed in para. 2.04 can be considered on a case-by-case basis.

3.02. In designing an effluent monitoring programme, particular attention should be given to the nature of the effluents from the nuclear facility under consideration and the potential for unplanned releases.

3.03. Nuclear facilities in general produce airborne and liquid effluents, but the nature and amount of radioactivity in the discharges and the potential for unplanned releases vary greatly from one facility to another. The most important types of nuclear facilities, with a description of their typical releases and effluent monitoring requirements, are discussed in paras 3.05—3.15.

3.04. The general aspects of monitoring programmes which are common to different types of facilities and modes of discharge are discussed in paras 3.16—3.24. In paras 3.25—3.54 more detailed information is given on the specific aspects of the monitoring systems.

TYPES OF NUCLEAR FACILITIES AND THEIR EFFLUENTS

3.05. Effluent monitoring is required in all of the nuclear fuel cycle facilities, ranging from processing of uranium ore to reprocessing of spent fuel. Other types of facilities, such as radioisotope laboratories and certain particle accelerators, will also require some form of effluent monitoring.

3.06. The different types of nuclear facilities at present in operation can be classified in the following groups which differ from each other from the point of view of the nature and amount of radionuclides discharged to the environment:

- Nuclear power plants
- Nuclear fuel reprocessing facilities
- Uranium handling facilities
- Plutonium handling facilities
- Research reactors
- Radiochemical facilities, including nuclear medicine and other laboratories handling radioactive materials
- Particle accelerators
- Treatment and storage facilities for radioactive wastes.

3.07. The modes of discharge in these groups are very similar. In almost all such facilities, airborne effluents are discharged through one or more stacks,
and liquid effluents are generally released through a pipe or canal into an appropriate sewage system or directly into a body of water. The rates of discharge may vary. Airborne effluents are, for the most part, discharged continuously, although in some facilities the releases may be discontinuous (batch), for example during shut-down operations. On the other hand, liquid effluents are almost always discharged discontinuously, on a batch basis, and only a few radiologically less important effluent streams are released continuously to the drainage system.

3.08. The most important radionuclides in airborne effluents from power reactors are the noble gases and radioiodines with, in addition, some fission and activation products in particulate form and volatile compounds of tritium and \( ^{14}C \). The use of special gas treatment systems in the newer power reactor facilities substantially reduces the discharge of noble gases, with the result that \(^{131}I\), even though released in small quantities, is the most radiologically significant nuclide present in the effluent stream. An accidental release might take the form of a complex mixture of fission products, but \(^{131}I\) and noble gases would still be among the most important nuclides to be monitored. The situation is different for research or experimental reactors where, depending on the type of reactor, the normal effluents could contain various nuclides, such as \(^{41}Ar\) and \(^{3}H\), but in general do not contain fission products. Fission products would, however, be the radionuclides of concern in an accidental release.

3.09. The normal airborne effluents from a reprocessing plant contain in particular long-lived fission and activation products, \(^{3}H\), \(^{14}C\), \(^{85}Kr\), \(^{129}I\), as well as isotopes of the actinides and some other fission or activation products. The effluents from radiochemical facilities and from uranium and plutonium handling facilities may contain practically all types of radionuclides present in the facility. The ratios in which the radionuclides are present in the effluents may vary according to the different decontamination factors provided by the waste treatment system for the various nuclides. In chemical and mechanical accidents such radionuclide ratios are generally maintained, although the total activities released may be higher. In criticality accidents, however, fission products, mostly short-lived, may be added to the release.

3.10. Certain particle accelerators produce some airborne effluents, including \(^{3}H\) and short-lived activation products in particulate form.

3.11. The liquid effluents from power reactors contain fission and activation products, with the isotopes of cobalt, strontium, caesium and iodine, together with tritium, predominating.

3.12. The liquid discharges from research and experimental reactors are generally very small and the type of reactor will influence the ratio between the various nuclides present.

3.13. The liquid waste waters from reprocessing facilities contain long-lived fission and activation products, such as \(^{3}H\), \(^{90}Sr\) and \(^{137}Cs\), together with isotopes of the actinides. The amounts and composition of the radionuclides in the liquid...
effluents will vary from plant to plant, depending on the waste treatment methodology applied.

3.14. (a) The liquid effluents from radiochemical facilities and from uranium and plutonium handling facilities may contain almost all the types of nuclides handled in the facilities, with ratios that cannot be foreseen and are dependent on the type of waste treatment system employed.

(b) The liquid effluents from uranium mining and milling contain primarily $^{226}$Ra and its daughter products.

(c) Particle accelerators do not normally produce significant amounts of liquid effluents, but possibly some tritium and short-lived activation products may be released.

3.15. Unplanned releases of liquids may arise from leaks and malfunctioning in waste collection and treatment systems, and they might generally show the same radionuclide composition and ratios as the normal effluents.

PRINCIPLES OF EFFLUENT MONITORING

3.16. Nuclear facilities are operated in accordance with their licensing conditions which in general include a requirement to minimize as far as practicable any discharge of radioactive effluents. It must be understood that compliance with this basic principle of radiation protection is mainly attained by good design of the nuclear facility, including the provision of efficient retention systems for radioactive materials and the careful adherence to good operational procedures.

3.17. The main principle to be observed for achieving the objectives given in Section 2 is that, for a nuclear facility, every effluent stream in which radioactive contamination can be foreseen should be put under routine surveillance at the point of final discharge.

3.18. There are in general a number of in-plant monitoring locations which provide the operator of a nuclear facility with important information on possible discharges of radioactive materials in the effluents. This information is used by the operator of a nuclear facility as a basis for decisions on plant operation. The effluent monitoring programme, however, must be independent of the in-plant monitoring programme and should be designed to give all the information needed to comply with the above-mentioned objectives.

3.19. Each type of nuclear facility, with its own characteristic discharges, will require a specific type of monitoring; for example, the type of sampling and measurement and the necessary measuring range will depend largely on the composition and the potential quantities of radioactive substances in the effluents. However, for all monitoring programmes it is necessary to decide upon:
   - The location of the monitoring points
   - The frequency of sampling and measurement
   - The radionuclides to be monitored.
3.20. The monitoring points are chosen in such a way that the results of monitoring are representative of the actual discharges. Such points are generally situated downstream of the effluent treatment systems in all the effluent streams discharging radiologically important radionuclides to the environment. Specific release points may be exempted from monitoring only if the extent of planned releases and the likelihood of unplanned releases from them are trivial from the point of view of radiation protection.

3.21. The frequency of sampling and measurement is determined by the variability of the effluent discharge rate and the likelihood of unplanned releases, as discussed in Section 4.

3.22. As mentioned above, the radioactivity present in effluents may vary widely with regard to the types and concentrations of the nuclides. Sampling and measurement methods should be chosen on the basis of a careful review of the anticipated radionuclide mixtures. They should be designed to cover at least those radionuclides which are most important from the radiation protection point of view and, in every case, the specific radionuclides explicitly mentioned in the discharge limits granted by the regulatory authority. Where the safety analysis report of the plant suggests the possibility of some other specific nuclides being released in case of an accident, some supplementary form of emergency monitoring for those particular nuclides may be useful.

3.23. Gross activity measurements, i.e. for total alpha and total beta/gamma activity, are in general undesirable, except perhaps for the noble gases, but they may be adequate when the radionuclide composition of the effluents is sufficiently well known and constant for the gross activity measurements to be an acceptable indication of the activities of the specific radionuclides released. Gross activity measurements are also acceptable when the activities released are so low that specific measurement of radionuclides is not feasible or not necessary but some confirmation is needed that the activity levels are low. The naturally occurring radionuclides that may be present must be taken into account.

3.24. Special monitoring problems may arise when low-energy beta emitters, such as $^3$H, $^{14}$C, $^{35}$S, or weak gamma emitters, such as $^{55}$Fe, are present.

**MONITORING OF AIRBORNE EFFLUENTS**

3.25. The first step in designing a monitoring programme for airborne effluents is to analyse the flow diagram of the ventilation and off-gas systems, in order to select the appropriate monitoring point in each airborne effluent stream or at the stack leading directly to the atmosphere, downstream of all filtering systems, where it is possible to obtain a representative sample of the radionuclides present in the effluent stream. The selection of the most suitable location of the
monitoring point is generally based on the requirements of representativeness of sampling, taking into account accessibility and feasibility of sampling. Some practical advice on the selection of monitoring points is given in Section 4.

3.26. To permit the selection of satisfactory monitoring points and of sampling systems with suitable characteristics, the flow diagram should provide all necessary information on flow-rate, pressure differentials, temperatures, humidity, effluent velocity, and so on.

3.27. The radioactive characteristics of the materials to be released and their variation with time must be taken into account in order to decide upon the most appropriate sampling and measurement rate and the extent of the additional information required, as mentioned in the previous paragraph.

3.28. In many cases, therefore, radioactivity monitoring must be supplemented by continuous or periodic measurement of some other relevant physical and chemical parameters which are necessary for the appropriate evaluation of the monitoring results, such as the air flow-rate and the temperature and humidity in the stack and in the sampling line, the chemical composition of the effluent stream, and the particle size distribution.

3.29. When there is a significant potential for unplanned releases, some additional measurement of relevant meteorological parameters, such as wind speed and direction, and temperature gradient, should also be included in the monitoring programme.

3.30. Some examples of basic monitoring requirements for particular types of facilities are discussed below.

Nuclear power plants

3.31. The typical monitoring system for nuclear power plants includes continuous measurement of the noble gases and continuous sampling of $^{131}$I and particulates. The periodic measurement of the samples of $^{131}$I and particulates in the laboratory is, in general, considered sufficient and will be more accurate for low release rates.

3.32. Normally, only those mixtures of radionuclides and specific nuclides that are named in the authorization are routinely monitored. However, it may be necessary to carry out periodically a detailed analysis of the overall radionuclide composition. Additional monitoring may be required for special nuclides such as $^3$H and $^{14}$C.

3.33. Any accident in a power reactor may involve the release of large quantities of noble gases. The continuous measurement of such gases required for normal operating conditions must also be adequate for the detection of accidental releases and therefore have a sufficiently wide measuring range.
Nuclear fuel reprocessing facilities

3.34. Because of the different characteristics of the radionuclides that may be discharged to the atmosphere, several types of monitoring are required. Continuous monitoring is necessary for the noble gases, and continuous sampling for radioiodines and tritium and for particulates. For the direct monitoring of effluent releases under normal operating conditions, continuous measurement of $^{85}$Kr and of $^{131}$I at the stack is generally considered to be sufficient. For the nuclides sampled on a continuous basis, periodic measurements in the laboratory are necessary for $^3$H, $^{14}$C, $^{129}$I, $^{131}$I, the actinides and the other beta/gamma-emitting particulates.

3.35. Such a monitoring system must also satisfy the requirements for alarm monitoring in case of an accidental release.

Uranium handling facilities

3.36. The monitoring problems concern essentially the presence of alpha-emitting particulates in the effluents. The monitoring programme should therefore be based on continuous sampling systems for aerosols. Such monitoring devices should have a measuring range wide enough to cover adequately both normal and abnormal releases.

Plutonium handling facilities

3.37. The monitoring problems again concern essentially the presence of alpha-emitting particulates in the effluents. The monitoring programme should be based on continuous sampling systems for aerosols, with continuous measurement at the stack. Again, the monitoring systems should have a measuring range wide enough to cover adequately both normal and abnormal releases.

3.38. Some facilities of this group may present the risk of a criticality excursion. For such an accident, in-plant monitoring systems should be provided.

Research reactors

3.39. The monitoring system necessary for normal operating conditions is generally not very different from that required for power reactors. However, the spectrum of possible accidental releases is wider, depending on the particular type of reactor and the kind of experiments that are performed. For example, if the reactor is also used for the production of radioisotopes, or if it is associated with experimental arrangements that can give rise to the accidental dispersion of specific radionuclides independently of the behaviour of the core, it would be necessary to provide sampling and measurement equipment for the detection of those...
specific nuclides. Such radionuclides could be dispersed in particulate form, and aerosol measurement would then be necessary. In this case, special, sensitive, continuous measuring methods might be required to permit quick detection of the dispersed radionuclides.

Radiochemical facilities, including nuclear medicine and other laboratories

3.40. As a general principle, the monitoring programme should be adapted to the particular radionuclides handled in the facility or laboratory. Noble gases are usually monitored only in effluents from large hot cells in which specimens of irradiated fuel are handled, while other airborne radioactive substances, such as tritiated water vapour or carbon-14 dioxide, may necessitate continuous monitoring in some very specialized laboratories. Radioactive halogens and aerosols are commonly present in almost all such facilities. In all cases, continuous sampling of the various relevant nuclides should be mandatory, while continuous measurement at the stack may be required only for hot cells used for the production of radioisotopes or for metallurgical examination.

3.41. The foreseeable unplanned releases from facilities of this type would generally have the same composition as the effluents under normal operating conditions, but at a higher level of activity. The same continuous monitoring devices may therefore cover the needs for both planned and unplanned releases, provided that the range of the measuring instruments is sufficiently wide.

Particle accelerators

3.42. Particle accelerators, in general, give rise only to limited effluent monitoring problems. Some form of monitoring system is recommended for certain types of accelerators. Such monitoring may be based on continuous sampling of particulates, with additional sampling of tritium in the case of neutron generators in which tritium targets are used. In general, continuous measurements are not required for particle accelerators.

MONITORING OF LIQUID EFFLUENTS

3.43. Several requirements of the monitoring programmes for radioactive liquid effluents are in principle similar to those of the monitoring programmes for airborne effluents, and the same general principles have to be applied when establishing an adequate programme. It is therefore necessary, as a first step, to analyse the flow diagram of liquid effluents in order to define the appropriate monitoring points in the network of tanks and discharge lines.
3.44. The flow diagram should provide the necessary information to permit selection of the most appropriate monitoring programme, including the volumes of the waste tanks and basins, the physico-chemical characteristics of the various effluent streams, and their expected production and discharge rates.

3.45. In general, the various types of liquid effluents produced in a nuclear facility are collected, according to their radioactive and chemical characteristics, in separate tanks or basins, and treated, as necessary, before discharge to the environment. The radioactive waste waters are then discharged on a discontinuous (batch) basis, to a pipe or canal which leads to a body of water.

3.46. The discharge of any such batch can be carried out only under appropriate control which ensures that the authorized discharge limit will not be exceeded. This requires that each batch be subjected to appropriate monitoring procedures which include the taking of a representative sample of each batch and the measurement of its radioactivity content before discharge. Continuous measurement of the discharge rate, with provision of automatic termination of the discharge, may also be appropriate to prevent abnormal releases.

3.47. The type of measurement required will depend on the way in which the discharge limit is specified and on the anticipated nature and amounts of radionuclides to be discharged.

3.48. If the discharge limit is given in the form of a discharge formula, the measurement should determine the activities of the specific nuclides explicitly mentioned in the discharge formula.

3.49. On the other hand, if these conditions do not apply, or if a specific radionuclide analysis cannot, for technical reasons, be obtained in due time, at least a gross activity measurement should be made on each batch before discharge. Where samples of the batch release have been taken before discharge, for gross activity measurement, the measurement of the specific radionuclides can be performed at a later stage for reporting purposes.

3.50. In any case, since the chemical nature of the mixture of liquid effluents in the batch may vary and the suspended matter present may cause enrichment and sedimentation effects, particular attention must be given to ensuring the homogeneity of the sample, in order to achieve adequate representativeness.

3.51. In the case of large discharges of radioactive liquid effluents to a receiving body of water, the competent authority will often require a final monitoring point downstream of all possible release pathways, for example, in the water outlet system just before the mixing of the effluent with the receiving water body. Continuous collection of samples proportional to the volume discharged should take place at this point, followed by periodic laboratory analysis of the radionuclide composition of the samples. In some facilities, only very low-level liquid effluents are produced; in such cases some relaxation of the requirement for continuous sampling in the discharge line may be acceptable.
3.52. If the features of the nuclear facility and its waste treatment system suggest a significant potential for unplanned releases, the continuous sampling in the discharge line should be supplemented by continuous direct measurement for alarm purposes.

3.53. From some facilities small amounts of radioactivity may, on occasions, be continuously discharged in effluents other than process or industrial wastes, for instance through sewage or rainwater drains. In such cases, because of the minor radiological importance of these effluents, continuous sampling in these secondary lines may not be necessary.

3.54. The various nuclear facilities discussed in paras 3.31–3.42 in connection with the monitoring of airborne releases have generally similar characteristics for the release of liquid effluents, and the selection of the types of sampling and measurement for particular facilities is governed by the same considerations as those described in paras 3.25–3.42.

4. SAMPLING AND MEASURING TECHNIQUES FOR EFFLUENT MONITORING

TYPES OF MONITORING

General

4.01. To satisfy the objectives and design principles mentioned in Sections 2 and 3, effluent monitoring must provide data on the actual discharge conditions and on the nature and amount of radioactivity released.

4.02. Effluent monitoring is based on two kinds of techniques:

(a) The use of probes set either in the airborne or liquid effluent stream (immersed probe) or outside but close to the release duct. In these cases, monitoring provides direct measurement of the effluent radioactivity. Contamination of probes may, however, introduce some difficulties.

(b) Sampling of the airborne or liquid effluent and measuring the radioactivity of this sample. Such measurements may be gross or selective.

4.03. These monitoring techniques permit alternative modes of operation. In the first, the measuring equipment gives a direct response to the operator of the facility and may be connected to warning devices in order to enable the operator to take corrective actions if necessary. The second mode involves in-situ or laboratory measurement after sampling. Both measurement techniques may be used in certain cases to supplement each other.
4.04. The sampling method of airborne and liquid effluents must be such that representative samples are obtained. The measurement procedures must provide sufficient reliability, accuracy and comparability of the results.

Airborne and liquid effluent monitoring

4.05. The types of monitoring to be carried out for both airborne and liquid effluents should take into account radiological protection requirements and other technical considerations as well.

4.06. For airborne effluents the types of monitoring can include gross measurements of beta/gamma-emitting aerosols, alpha-emitting aerosols and noble gases, and specific measurements of radioisotopes such as iodine, strontium and tritium. For liquid effluents, the types of monitoring can include gross measurements of beta/gamma-emitting radionuclides and alpha-emitting radionuclides, and specific measurements of radioisotopes, in particular iodine and tritium.

4.07. Gross measurements of alpha- and beta/gamma-emitting aerosols in airborne effluents or gross measurements of alpha- and beta/gamma-emitting radionuclides in liquid effluents should be supplemented periodically by specific nuclide measurements, possibly carried out in the laboratory or in situ, with the aim of determining the isotopic composition of the effluents released.

4.08. As discussed in para. 3.23, gross activity measurements are in general undesirable; with certain exceptions, specific nuclide analyses are preferred.

4.09. For certain specific radionuclides, monitoring may be designed to provide information on the chemical and physical forms in which they are present. For example, special cartridges may be used for sampling the different species of iodine.

SAMPLING TECHNIQUES

4.10. When effluent monitoring is based on the analysis and/or measurement of collected samples the sampling techniques referred to in paras 4.11–4.32 are generally used.

Sampling points

4.11. The sampling procedures should take account of the following principles:

(a) Since the measurements should indicate the radionuclides that are actually released to the environment, the sampling point should be located where it is likely to provide a representative sample.
(b) The sample collection methods should be designed to obtain samples which are qualitatively identical and quantitatively proportional to the radioactivity content of the effluent discharged.

4.12. Special attention must be given to ensuring the representativeness of the samples, even under special conditions of operation and release, such as, for example, small flow-rate in the ventilation system under emergency conditions.

Types of sampling

4.13. Different types of sampling can be used which take into account the operating and release conditions, the design of the release system and equipment, the type of release, the nature of the materials to be measured, etc. The sampling can be continuous, periodic, special, or self-actuated.

4.14. Continuous sampling is required when there may be wide variations in the concentration of the radionuclides or in the discharge-rate of the effluents, or when the likelihood and potential consequences of unplanned releases are not trivial.

4.15. Periodic sampling may be sufficient when the concentrations of all radionuclides are relatively constant and when unusual variations are unlikely. Periodic sampling may be actuated automatically. The frequency of such sampling should be periodically reconsidered.

4.16. Special sampling is carried out, whenever necessary, to monitor either special releases required by operational conditions or unusual occurrences.

4.17. Self-actuated sampling is accomplished by devices which automatically collect samples when sharp variations occur in the concentration of the radionuclides released. Actuation of such sampling may be automatically linked to devices which directly measure the radioactivity level of airborne and liquid effluents.

Sampling methods and techniques

Airborne effluents

4.18. In the case of airborne effluents, the sampling methods to be used depend upon the types of monitoring required (see paras 4.05—4.09).

Airborne aerosols

4.19. For monitoring airborne aerosols, the sample is extracted from the discharge stream at a point where the effluent is reasonably well mixed and the flow is non-turbulent. Isokinetic sampling, where the linear flow-rate in the sampling line is about the same as that in the discharge stream, should be used.
where possible. The sampling nozzle should be so located that a representative sample of the air stream is obtained. In general, the sampling system should be so designed that deposition of particles in the sampling line is minimized. For example, the length of the sampling line between the sampling point and the filter should be as short as possible and have as few bends as possible. The deposition of particles in the duct should be determined experimentally.

4.20. The aerosol filter may either be fixed in position or moved continuously or intermittently.

4.21. Fixed- or moving-filter sampling systems can be used in association with a detector, mounted above the filter, which measures continuously gross alpha or beta/gamma activity. An advantage of the moving-filter system is that measurements can be made of gross alpha or beta/gamma activity at a point along the moving filter at a distance from the point of collection that permits sufficient decay of the naturally occurring daughter products of radon and thoron, together with any solid daughter products of the radioactive noble gases. Difficulties are sometimes encountered owing to the effects of acids and solvent vapours in the air stream on mechanisms of the moving-filter system. Because of the longer collection time, the sensitivity of the fixed-filter system can be greater. In addition, individual samples may be removed after a prescribed period of time and the collected radioactivity assessed in the laboratory using low-background counting techniques.

Iodine

4.22. Radioactive isotopes of iodine may be present in the air stream in physical and chemical forms which penetrate the aerosol filters. These different species may, however, be trapped by drawing the sample stream, after the aerosol filter, through special iodine-collecting materials, such as activated charcoal, silver zeolites or other suitable substances. To improve the collection of the different physical and chemical forms of iodine the charcoal may be treated with chemical products such as potassium iodide (KI) or triethylene diamine (TEDA). Nevertheless, the collection efficiency might be affected by physical parameters such as the temperature of the air sampled or the presence of organic or water vapours (see, for example, Ref. [4]). The efficiency may also decrease during a prolonged sampling period.

Noble gases

4.23. When the activity concentration of the noble gases is sufficiently high, sampling of the adequately filtered effluent stream in a container of appropriate volume, at atmospheric pressure, may be sufficient.
4.24. Another method is to take a sample of the noble gases by using compressors, a technique which permits filling a suitable sampling container at a high pressure, and also collecting a large quantity of gas in a small volume, to provide greater sensitivity.

4.25. When necessary, the sampling of noble gases can be performed by using a cold trap, for example activated charcoal at low temperature, which can accumulate in a small volume a considerable amount of these types of gases.

Tritium

4.26. Tritium may be present in an airborne effluent stream as tritium gas or as tritium oxide. Several methods may be used for assessing any tritium present in the filtered sample air stream. Tritium gas cannot be trapped as easily as tritium oxide and it must first be converted into tritium oxide by passing the air stream over heated oxide copper wool.

4.27. Among the methods currently used to trap tritium oxide the following may be mentioned:

- The use of a cold trap permitting the collection of tritium oxide vapour by condensation.
- The use of an appropriate chemical substance such as silica gel or other similar material to retain the tritiated water vapour.
- The use of a bubbling system in water. By isotopic exchange, the tritium oxide of the air stream is retained in the water.

Carbon-14

4.28. Carbon-14 may be present in airborne effluents in the form of gaseous compounds such as CO₂, CO, and CH₄ or other hydrocarbons. Sampling of ¹⁴C in airborne effluents can be done by taking samples in bottles or pressurized containers. Aluminized plastic bags may also be used. The latter methods will provide larger samples and a lower detection limit. However, continuous sampling over a week or a month may be preferable, as the short-term discharge rate of ¹⁴C compounds may vary widely, depending on the operating conditions.

4.29. Several methods may be used to measure the ¹⁴C activity discharged with the airborne effluents. One method is the direct measurement of the ¹⁴C in an effluent sample in a gas counter. Another method is to measure the ¹⁴C in these compounds as barium carbonate solubilized in a liquid scintillator. CO₂, CH₄ and the other hydrocarbons must be burned in a catalytic oven to transform them into CO₂; the CO₂ is then precipitated as BaCO₃ in a NaOH solution. In many cases, however, the sampling of ¹⁴CO₂ by absorption in NaOH will be sufficient.
Other specific radionuclides

4.30. Specialized methods are available, or should be developed as needed, for the selective sampling and measurement of other specific radionuclides.

4.31. Additional information on current sampling and measurement techniques for airborne contaminants with practical examples of their application will be found in another IAEA publication [5].

Liquid effluents

4.32. Representative samples of the liquid effluents should be collected. In most cases representative samples are collected from tanks of defined volume and later measured. To ensure that the collected samples are representative, the liquid in the waste tank should be circulated with pumps or sparged with air before sampling. To ensure representativeness of the sample collected, the quality and duration of the mixing should be adequate and the sample should include a proportional quantity of materials in suspension (insoluble substances). In the case of continuous sampling, care must also be taken to ensure the representativeness of the sample. In general, sampling proportional to the stream flow-rate is preferred. However, if the stream flow-rate is reasonably constant, periodic sampling may be sufficient.

Composite samples

4.33. To reduce the number of detailed measurements required to assess the radionuclides released, samples of batch releases of liquid effluents or samples of airborne contaminants may be composited proportionally to the volume of each batch release or to the flow-rate of the effluent stream. The period of collection for these composite samples should take into account the radioactive half-life of the radionuclides to be measured.

MEASUREMENT TECHNIQUES

In-situ measurements

4.34. The main aim of in-situ measurements is to provide immediate information on the concentration of radionuclides in the effluent stream and to actuate the associated warning systems in the event that the value exceeds a pre-set limit.
Gross and specific nuclide measurements

4.35. In the case of in-situ gross measurements, the beta/gamma or alpha activity in air or liquid streams or from collected samples is determined directly with appropriate counting assemblies, using probes equipped with detectors such as GM tubes, proportional counters, scintillation or semi-conductor detectors.

4.36. In-situ specific nuclide measurements can be made either directly or on collected samples using an appropriate probe such as a Ge(Li) semi-conductor detector connected to a multichannel pulse-height analyser. Where sampling is performed for the specific measurement of radioiodine, the activity of the sample can be measured using an appropriate counting assembly with or without a pulse-height analyser.

4.37. The results of specific nuclide in-situ measurements may contain significant errors when the effluent contains a considerable concentration of other radionuclides which are retained in the collected sample, for example fission gases in air sampled for the assessment of radioiodine. Under these conditions, the measurement of the radioactivity in the sample may require qualitative and quantitative analysis in the laboratory.

Characteristics of measurement assemblies

4.38. The range, thresholds and measurement accuracy of the assemblies used for continuous direct monitoring of the effluent released have to be such that these assemblies meet the requirements for monitoring under normal operating conditions and, in addition, the requirements for assessing the activity released in an emergency situation. Examples of the measurement characteristics of some assemblies are presented in detail in the publications of the International Electrotechnical Commission.

Associated warning devices

4.39. Continuous measurement apparatus should be equipped with warning devices with one or more triggering thresholds which may be adjusted at selected levels within the entire range of measurement.

4.40. One threshold may be set at a value just above that which corresponds to the level of the activity released in normal operation. Any actuation of this threshold will indicate an abnormal operating situation which may require corrective action. Another threshold may be set at a value corresponding to the maximum authorized release limit or at a fraction of this limit. Any actuation of this threshold will require some corrective action including, where appropriate, termination of the release and notification of the appropriate authority as required.
A special threshold set below the expected background level should be provided to indicate any instrument malfunction.

**Laboratory measurements**

4.41. Laboratory measurements are used either where effluent monitoring is accomplished by sampling only or in addition to in-situ measurements. They are often the only means of obtaining a complete analysis of all the individual radionuclides present in the effluent.

4.42. In the laboratory, the samples can be processed in such a way that the influence of interfering contaminants is reduced or eliminated and a concentrated sample suitable for measurement prepared. Laboratory measurements are thus capable of achieving a higher sensitivity than is possible with in-situ measurements.

4.43. The types of measurement assemblies to be used are generally those to be found in a radioactive analysis laboratory (see, for example, Ref. [6]).

**Computerized data processing and evaluation methods**

4.44. For extensive monitoring programmes to determine the presence of individual radionuclides in a complex mixture, use is often made of a semiconductor detector coupled to a multichannel pulse-height analyser. This permits the quick determination of a number of gamma emitters at the same time, with automatic spectrum data acquisition and the use of computerized evaluation methods for identification of a selected list of nuclides. To allow intercomparison of the results of such measurements, it is important to define precisely and report the detection limit and error limits for each radionuclide to be measured.

**Types of assemblies to be used**

*Airborne effluents*

4.45. For a summary description of the assemblies that can be used for the sampling and assessment of airborne effluents, reference is made to Table I.

*Liquid effluents* (in-situ monitoring)

4.46. Continuous gross beta/gamma measurements are performed directly in the effluent conduit or in a 'flow-through' receiver, with the beta/gamma probe immersed in the flowing liquid. A disadvantage of this method is the memory effect from possible residual contamination of the probe. GM counters and NaI(Tl) or plastic scintillators may be used as detectors. The counting efficiency
<table>
<thead>
<tr>
<th>Radioactivity in airborne effluents</th>
<th>Monitoring assembly</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Airborne aerosols</strong></td>
<td><strong>Sampling equipment</strong></td>
<td><strong>Detectors and electronic auxiliaries</strong></td>
</tr>
</tbody>
</table>
| A. Sampling on fixed filter paper, made of cellulose, glass or membrane | Diameter: 30 to 130 mm | Gross measurements | Counter window for alpha emitters: 1 to 2 mg/cm². Delayed measurements are required for decay of natural radioactivity. Beta/gamma emitters: Influence of background gamma radiation is minimized with shielding and eventually with anticoincidence circuits. Alpha emitters: Counting efficiency is influenced by dust deposition on the filter.
| Sampling time: membrane: approximately 1 day | Beta/gamma emitters: Plastic scintillation detector | (Self-) absorption has to be minimized: with the use of big-sized filters, membrane filters and limited sampling times. Cold ashing may be done to improve counting efficiency and spectral resolution. | Cellulose, glass fibre: 1 day to 1 week |
| B. Sampling on moving filter tapes, made of cellulose. | Tape width: 40 to 70 mm | Alpha emitters: ZnS (Ag) scintillation detector | Retention efficiency is dependent on the relative humidity, the temperature and the poisoning of the charcoal with organic vapours. Shielding is required against gamma radiation background. | Rate of movement: a few cm/h |
| Flow-rate of the air: variable between 20 and 200 l/min, according to size and type of the filter paper. | End-window GM counter | For sampling of iodine isotopes with charcoal cartridges the residence time is determined from the relationship: | Retention efficiency: between 75 and 99%, according to cellulose, glass fibre or membrane filters. | |
| Sampling time: cellulose or glass fibre: 1 day to 1 week | Proportional flow counter | Sampling medium volume | Flow-rate of air > 0.25 s. | |
| **Iodine** | | | If only iodine is present: counters for gross beta/gamma measurements. Selective measurements with: NaI scintillation detector for mono-channel measurements at gamma energy of 360 keV. | |
| Sampling on activated and impregnated (KI, TEDA) charcoal, placed in typical cartridges, with a residence time of at least 0.25 s. | Electronics: Logarithmic rate meter with four decades (at least). | Gamma-spectrometric analysis in the laboratory: necessary in the case of important loading of the sampling medium by fission products, noble gases, etc. | The accumulated activity or incremental values are determined. | |
| Filter paper, impregnated with activated charcoal, is also used, especially to collect iodine, deposited on solid particles and elementary iodine. | Gamma-spectrometric analysis in the laboratory: necessary in the case of important loading of the sampling medium by fission products, noble gases, etc. | The retention efficiency is dependent on the relative humidity, the temperature and the poisoning of the charcoal with organic vapours. Shielding is required against gamma radiation background. | Sampling on silver-impregnated molecular sieves, placed in typical cartridges. | |
| Sampling on silver-impregnated molecular sieves, placed in typical cartridges. | Retention efficiency > 90% for iodine in the inorganic form. | The retention efficiency is dependent on the relative humidity, the temperature and the poisoning of the charcoal with organic vapours. Shielding is required against gamma radiation background. | Sampling time: approximately 1 to 2 weeks | |
| Retention efficiency: between 75 and 99%, according to cellulose, glass fibre or membrane filters. | Volume of sampling medium: 10 to 100 cm³. | For sampling of iodine isotopes with charcoal cartridges the residence time is determined from the relationship: | Flow-rate of the air: a few litres/min to 50 l/min. | |
| Sampling on activated and impregnated (KI, TEDA) charcoal, placed in typical cartridges, with a residence time of at least 0.25 s. | If only iodine is present: counters for gross beta/gamma measurements. Selective measurements with: NaI scintillation detector for mono-channel measurements at gamma energy of 360 keV. | The accumulated activity or incremental values are determined. | The retention efficiency is dependent on the relative humidity, the temperature and the poisoning of the charcoal with organic vapours. Shielding is required against gamma radiation background. | |
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### TABLE I (cont.)

<table>
<thead>
<tr>
<th>Radioactivity in airborne effluents</th>
<th>Monitoring assembly</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Noble gases</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>In-situ measurement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flowing through an ionization chamber or through a proportional counter: the air to be measured is mixed with the chamber filling gas (volume 5—20 l).</td>
<td>Ionization chamber with flow-through (5—20 l).</td>
<td>Preceding dust filtration is required.</td>
</tr>
<tr>
<td>Flowing through a recipient, in which the detector is immersed (volume 5—20 l).</td>
<td>Proportional flow counter (PFC).</td>
<td>The accuracy and the sensitivity of the measurements are dependent on the energy of the beta emitters.</td>
</tr>
<tr>
<td>Flow-rate of the air: 10—100 l/min.</td>
<td>GM counter, Scintillation detector (SD), NaI or plastic scintillator.</td>
<td>Shielding is required against gamma radiation background.</td>
</tr>
<tr>
<td><strong>Laboratory measurement</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sampling in a container: at atmospheric pressure or with compression.</td>
<td>Ionization chamber with flow-through (volume: 1—10 l) with the possibility of creating a vacuum.</td>
<td></td>
</tr>
<tr>
<td>Introduction of the air to be measured in one of the three systems mentioned above.</td>
<td>Proportional flow counter.</td>
<td></td>
</tr>
<tr>
<td>Sampling on a cold trap.</td>
<td>Gamma-spectrometric analysis for identification of radionuclides and measurements of activity concentration.</td>
<td></td>
</tr>
<tr>
<td>Ge(Li) detector and multichannel pulse-height analyser.</td>
<td>Electronics: Direct-current amplification for the ionization chambers.</td>
<td></td>
</tr>
<tr>
<td>Scintillation detector (SD), NaI or plastic scintillator.</td>
<td>Logarithmic ratemeter with four decades (at least) for PFC or SD.</td>
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</tr>
<tr>
<td>Radioactivity in airborne effluents</td>
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</tr>
<tr>
<td>Sampling equipment</td>
<td>Detectors and electronic auxiliaries</td>
<td></td>
</tr>
<tr>
<td><strong>Tritium</strong></td>
<td>Differential ionization chambers with compensating circuits.</td>
<td>Preceding dust filtration is required.</td>
</tr>
<tr>
<td>In-situ measurement</td>
<td>Proportional flow counter.</td>
<td>In-situ measurements are influenced by other sources: background and eventually noble gases; therefore compensating circuits are applied.</td>
</tr>
<tr>
<td>The first two systems for noble gases (ionization chamber or proportional counter with flow-through) can be used.</td>
<td>Liquid scintillation counting.</td>
<td>Memory effects can appear: remaining contamination on the detector after the flow-through of gases with high tritium concentrations.</td>
</tr>
<tr>
<td>Flow-rate of the air: 1–10 l/min</td>
<td>Ionization chamber.</td>
<td>Samples are to be measured in the laboratory by liquid scintillation counting in order to determine the tritium concentration. Temperature and relative humidity at the sampling point have to be determined.</td>
</tr>
<tr>
<td>Laboratory measurement</td>
<td>Proportional counter.</td>
<td></td>
</tr>
<tr>
<td>Sampling of tritiated water:</td>
<td>Electronics: The same as for noble gases.</td>
<td></td>
</tr>
<tr>
<td>by freezing on cold surfaces</td>
<td></td>
<td></td>
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<tr>
<td>by adsorbing on silicagel</td>
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<tr>
<td>by trapping in a water bubbling system</td>
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<tr>
<td>The water is measured by liquid scintillation counting or the water is decomposed and the HT activity is measured.</td>
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</tbody>
</table>
is dependent on the energy of the emitted radiation and the geometry of the
counting system (including self-absorption).

4.47. Continuous gross beta/gamma measurements can be carried out directly
above the upper surface of a shallow liquid stream. The detector to be employed
is either a scintillation detector or a flow counter with an effective surface
covering the entire width of the liquid stream. For this method also, the counting
efficiency is dependent on the energy of the emitted radiation and on the geo-
metry of the counting system (including self-absorption).

4.48. Gross alpha and beta/gamma measurements can also be carried out by
drawing samples continuously from the effluent stream directly on to either a
metal dish (aluminium or stainless steel) or on to a moving special filter tape
which is then passed through a water-evaporating device. The activity of the dried
solid matter is directly measured by passing the metal dish or the moving filter
tape under the appropriate detector.

QUALITY CONTROL

4.49. Quality control shall be applied to the sampling and measurement
procedures to give assurance of the representativeness of sampling and the validity
of the measurement results.

Calibration procedures

4.50. The calibration of measuring assemblies used for in-situ or laboratory
measurements should be performed on a regular basis, using reference standards,
or secondary standards that have been calibrated against reference standards. The
frequency of calibration should take into account the reproducibility of response
and stability with time of the assemblies.

4.51. Continuous monitoring assemblies should be calibrated against
appropriate standards to establish the relationships between the concentrations
and the indications given by those assemblies over the full measuring range to be
covered by the instrument. These relationships are to be based on the isotopic
composition of the radioactive effluent monitored.

4.52. The dates and the results of calibration operations must be recorded.

4.53. Checks of instruments to demonstrate only their proper functioning
may be performed with radioactive sources that are not standards.

Periodic testing procedures

4.54. Periodic testing of the calibration of the assemblies and of the
analytical procedures should be performed by different methods and with cross-
checks against other independent measurements.
Intercomparison measurement programmes

4.55. It is recommended that nuclear facilities with effluent monitoring programmes take part in national or international intercomparison measurements on a regular basis.

5. RECORDING AND REPORTING OF MONITORING RESULTS

GENERAL

5.01. The recording and reporting of monitoring data and related information should be accomplished in a manner that satisfies the objectives described in Section 2, para. 2.03.

5.02. Monitoring data must be recorded in the units of measurement that are actually given by the counting and monitoring instruments. Other values calculated or derived from these data may be recorded in addition to, but not in place of, the measured values.

5.03. The reports of monitoring results must be expressed in a form which facilitates comparison with the applicable authorized limits or standards.

5.04. The results of effluent monitoring should be reported periodically, but not less frequently than once per year. The details of the reporting procedure will be established by the regulatory authority. More detailed and more frequent reporting will be required for those facilities that release radiologically important quantities or concentrations of radioactive materials.

RECORDING OF EFFLUENT MONITORING RESULTS

5.05. Monitoring data for each type of effluent (airborne or liquid) should be obtained and recorded in such a way that the data can be reported in a uniform manner.

5.06. A uniform recording procedure should be established which specifies the units of measurement to be recorded and provides generally defined guidance for recording appropriate supplementary information such as that listed in para. 2.04. The need for supplementary information should be determined for each facility on a case-by-case basis and should enable raw measurement data to be reported in a way that satisfies the objectives in Section 2. The supplementary
data should minimize the possibility of errors in interpreting the results and facilitate processing and compiling of reported data.

5.07. Records of monitoring data should include:

- Name of installation;
- Type and source of effluent;
- Points of release;
- Points of measurement and sampling;
- Special radionuclide, or radionuclide mixtures, released;
- Time and duration of release;
- Effluent flow-rate;
- Total volume of effluent (during period of sample);
- Volume of sample (including sampling error where possible);
- Time and duration of sample;
- Description of measurement technique;
- Time of measurement;
- Actual measured results, including measurement error or accuracy and minimum detectable limit.

5.08. It will be useful to record additional data as follows:

- Flow-rate of receiving water (liquid effluents);
- Height of release (airborne effluents);
- Meteorological data, such as wind direction, wind speed, atmospheric stability, precipitation;
- Fraction of applicable authorized release limits or standard actually released.

5.09. In the case of batch releases, the above-mentioned data should be recorded for each release.

5.10. If unplanned releases occur, the available data mentioned in paras 5.07 and 5.08 should be recorded. The causes of the unplanned releases should also be recorded.

5.11. The recording of counting and sampling results should be subjected to statistical analysis which will accurately describe the limits of error and the confidence limits of the data.

REPORTING OF EFFLUENT MONITORING RESULTS

5.12. The measurements of radioactivity in releases must be interpreted in terms which can be directly compared with the applicable authorized limits or standards. Consequently, the way in which the authorized limits or standards are expressed will determine the way in which the data are presented, in order to demonstrate compliance with the authorized limits or standards (see para. 2.03(a)).

2 If the radioactivity in the sample is less than a minimum detectable level of measurement, the values should be reported as "equal to or less than the minimum detectable limit".
5.13. In addition, measurement data will be required to provide information that will satisfy the objectives in para. 2.03.

5.14. Although it does not seem to be practicable or indeed necessary to attempt to influence the form in which authorized limits are expressed, there are clear advantages in reporting the data on quantities and/or concentrations of activity in effluents discharged to the environment in a uniform manner.

5.15. In general, airborne and liquid effluent releases to the environment must be reported for each release period together with the duration of the release. The report must provide the total activity of specific radionuclides or radionuclide mixtures discharged during the reporting period.

5.16. The reported information for both airborne and liquid effluent releases should also include a summary description of the methods used for sampling and measurement together with estimates of the overall errors associated with the recorded measurements.

5.17. Where gross alpha, gross beta or gross gamma activity measurements have been made, the reported information on discharges should describe the assumed mixture of nuclides and the basis for this assumption.

5.18. To accomplish the objectives described in para. 2.04, the report could include additional information such as that indicated in para. 5.08.

5.19. Where unplanned releases of radioactivity have occurred, the relevant data mentioned in paras 5.07 and 5.08 and the causes and consequences of the unplanned releases should be reported.

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General


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Annex 1

EXAMPLES OF
PROCEDURES AND EQUIPMENT FOR MONITORING
RADIOACTIVE AIRBORNE AND LIQUID RELEASES
FROM NUCLEAR FACILITIES

MONITORING METHODS FOR RADIOACTIVE NOBLE GASES IN
AIRBORNE EFFLUENTS FROM NUCLEAR POWER PLANTS

I. Winkelmann, Federal Republic of Germany

Two monitoring and measuring methods are applicable for radioactive noble gases at the stack of nuclear power plants:

1. Continuous measurement of emitted amounts of radioactive noble gases;
2. Measurement of individual nuclides of radioactive noble gases, with respect to calculating radiation exposure of the public in the vicinity of nuclear power plants.

CONTINUOUS MEASUREMENT OF NOBLE GASES

The release rate of radioactive noble gases can be monitored by a standardized measuring chamber. Such a measuring chamber may be equipped with a beta-sensitive plastic detector with a diameter of about 15 cm and a sensitive thickness of 0.5 mm. Suitable dimensions of the measuring chamber are 50 cm X 30 cm X 6 cm. The technical design of the measuring chamber has to ensure that an almost energy-independent measurement of beta activity is guaranteed within the range of about 100 keV to 2 MeV. With this measuring device, a low detection limit of $5 \times 10^{-7} \text{Ci/m}^3 \ (1.9 \times 10^4 \text{ Bq/m}^3)$ is achieved, corresponding to a measurable activity release of 0.1 Ci/h ($3.7 \times 10^9 \text{ Bq/h}$) at an air throughput of $5 \times 10^5 \text{ m}^3/\text{h}$ at the stack. Of course, other detector systems can also be used, e.g. a NaI(Tl) detector or a large-area flow counter. Figure A1-1 shows such a measuring chamber used for radioactive noble gases at the stack of nuclear power plants in the Federal Republic of Germany.

**TABLE A1-1. CALIBRATION FACTORS (K) FOR DIFFERENT NOBLE GASES**

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Detector</th>
<th>Large-area flow counter</th>
<th>NaI(Tl) detector</th>
<th>Plastic detector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar-41</td>
<td>(Ci • min/m³)</td>
<td>(1.8 ± 0.2) × 10⁻⁹ (6.7 ± 0.7) × 10</td>
<td>(2.5 ± 0.3) × 10⁻⁹ (9.3 ± 1.1) × 10</td>
<td>(2.6 ± 0.3) × 10⁻⁹ (9.6 ± 1.1) × 10</td>
</tr>
<tr>
<td></td>
<td>(Bq • min/m³)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kr-85</td>
<td>(Ci • min/m³)</td>
<td>(2.7 ± 0.9) × 10⁻⁹ (10.0 ± 3.3) × 10</td>
<td>(7.2 ± 0.8) × 10⁻⁸ (2.7 ± 0.3) × 10³</td>
<td>(2.0 ± 0.2) × 10⁻⁹ (7.4 ± 0.7) × 10</td>
</tr>
<tr>
<td></td>
<td>(Bq • min/m³)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xe-133</td>
<td>(Ci • min/m³)</td>
<td>(4.9 ± 0.7) × 10⁻⁹ (1.8 ± 0.3) × 10²</td>
<td>(2.8 ± 0.5) × 10⁻⁹ (1.0 ± 0.2) × 10²</td>
<td>(2.6 ± 0.4) × 10⁻⁹ (9.6 ± 1.5) × 10</td>
</tr>
<tr>
<td></td>
<td>(Bq • min/m³)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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The calibration factors shown in Table A1-1 were determined with a measuring chamber of the type shown in Fig.A1-2, equipped with a plastic detector, NaI(Tl) detector and large-area flow counter, and used for comparison measurements for different noble gases.

When a NaI(Tl) detector is used, it may be necessary to shield the measuring chamber by a few centimetres of lead to reduce background radiation.

MEASUREMENT OF NUCLIDE COMPOSITION OF THE RELEASE

To calculate radiation exposure of the public in the vicinity of nuclear power plants, the nuclide composition of the released noble gases is required. For this purpose, gamma-spectrometric analysis can be used, either by discontinuous or continuous measurement of the most important noble gases at the stack. In this context two aspects are important. First, to achieve a low detection limit, sample enrichment may be necessary. Second, quick measurement methods of the short-lived gaseous radionuclides are needed.
The following two measuring methods for individual radioactive gaseous nuclides at the stack of nuclear power plants are applied.

**Measurement with a pressure flask**

This measuring method is based on sampling air in a pressure flask with a compressor and immediate measurement with a Ge(Li) semi-conductor detector in connection with a multi-channel analyser. Sample enrichment in a pressure flask of a volume of, for example, 4 litres, up to 200 atmospheres, can be done within 8 to 15 min, depending on the pumping capacity of the chosen compressor. Lower detection limits, down to $4 \times 10^{-10}$ Ci/m$^3$ (15 Bq/m$^3$), can be reached. The method described here is mostly used at nuclear power stations to measure the radionuclide composition at the stack weekly or, in the case of high releases of noble gases, more often. Moreover, this method allows to take air samples in different plant media at any time in case of abnormal releases. A further advantage of this measuring procedure is the very good detection limit for long-lived nuclides. Figure A1-3 shows the air compressor unit with a pressure flask of 4 l volume.
<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Direct gamma-spectrometric measurement (Measuring period 30 min)</th>
<th>Pressure flask method (Measuring period 15 min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower detection limits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Ci/m³) (Bq/m³)</td>
<td>(Ci/m³) (Bq/m³)</td>
</tr>
<tr>
<td>Kr-89</td>
<td>$6.0 \times 10^{-8}$ $2.2 \times 10^3$</td>
<td>$4.5 \times 10^{-8}$ $1.7 \times 10^3$</td>
</tr>
<tr>
<td>Xe-137</td>
<td>$4.8 \times 10^{-8}$ $1.8 \times 10^3$</td>
<td>$1.9 \times 10^{-8}$ $7.0 \times 10^2$</td>
</tr>
<tr>
<td>Xe-138</td>
<td>$4.5 \times 10^{-8}$ $1.7 \times 10^3$</td>
<td>$3.5 \times 10^{-9}$ $1.3 \times 10^2$</td>
</tr>
<tr>
<td>Xe-135m</td>
<td>$2.0 \times 10^{-8}$ $7.4 \times 10^2$</td>
<td>$8.4 \times 10^{-10}$ $3.1 \times 10$</td>
</tr>
<tr>
<td>Kr-87</td>
<td>$3.1 \times 10^{-8}$ $1.1 \times 10^3$</td>
<td>$8.3 \times 10^{-10}$ $3.0 \times 10$</td>
</tr>
<tr>
<td>Kr-88</td>
<td>$3.9 \times 10^{-8}$ $1.4 \times 10^3$</td>
<td>$1.1 \times 10^{-9}$ $4.1 \times 10$</td>
</tr>
<tr>
<td>Kr-85m</td>
<td>$1.6 \times 10^{-8}$ $5.9 \times 10^2$</td>
<td>$5.8 \times 10^{-10}$ $2.1 \times 10$</td>
</tr>
<tr>
<td>Xe-135</td>
<td>$1.5 \times 10^{-8}$ $5.6 \times 10^2$</td>
<td>$4.0 \times 10^{-10}$ $1.5 \times 10$</td>
</tr>
<tr>
<td>Xe-133</td>
<td>$2.0 \times 10^{-8}$ $7.4 \times 10^2$</td>
<td>$2.7 \times 10^{-9}$ $1.0 \times 10^2$</td>
</tr>
<tr>
<td>Xe-133m</td>
<td>$1.4 \times 10^{-7}$ $5.2 \times 10^3$</td>
<td>$2.5 \times 10^{-9}$ $9.3 \times 10$</td>
</tr>
<tr>
<td>Ar-41</td>
<td>$1.5 \times 10^{-8}$ $5.6 \times 10^2$</td>
<td>$3.6 \times 10^{-10}$ $1.3 \times 10$</td>
</tr>
<tr>
<td>Xe-131m</td>
<td>$7.0 \times 10^{-7}$ $2.6 \times 10^4$</td>
<td>$2.0 \times 10^{-8}$ $7.4 \times 10^2$</td>
</tr>
<tr>
<td>Kr-85</td>
<td>$3.5 \times 10^{-6}$ $1.3 \times 10^5$</td>
<td>$8.2 \times 10^{-8}$ $3.0 \times 10^3$</td>
</tr>
</tbody>
</table>

Direct gamma-spectrometric measurement using a measuring chamber with a Ge(Li) semi-conductor detector

The sensitivity of large Ge(Li) semi-conductor detectors allows a direct gamma-spectrometric measurement of the radionuclide composition of noble gases without compression at the stack of nuclear power plants. This method is useful for measuring very short-lived gaseous radionuclides. Lower detection limits of $1.6 \times 10^{-8}$ Ci/m³ ($5.9 \times 10^2$ Bq/m³) can be obtained with a measuring chamber of 100 l volume using a Ge(Li) detector with a relative efficiency of 9.1% in respect to a NaI(Tl) detector for the 1332 keV gamma radiation of $^{60}$Co.
Table A1-II shows the lower detection limits obtainable with the measuring equipment described here and with the pressure flask method. In Fig.A1-4 the measuring chamber — a prototype for direct measurements of noble gases with a Ge(Li) detector — is shown.

**MONITORING OF RADIOIODINE IN GASEOUS EFFLUENTS AT THE BHABHA ATOMIC RESEARCH CENTRE, INDIA**

S. Krishnamony, India

For some time, at Bhabha Atomic Research Centre, radioiodine in the gaseous effluents of nuclear reactors and radiochemical plants has been monitored with cartridges containing activated charcoal. Recently, a modified version of a
device which is popularly known as the May Pack has been in use for monitoring radioiodine aerosols which are likely to exist in different chemical and physical forms.

**MONITORING OF RADIOIODINE IN AIR USING ACTIVATED CHARCOAL**

Activated coconut charcoal, crushed and sieved to obtain particles in the size range 14—22 mesh, is packed in a glass tube, 2 in long and with an internal diameter of $\frac{3}{4}$ in ($\sim 5$ cm X 1.3 cm dia.). The charcoal is held in the tube by means of two fine wire gauze pieces which in turn are held in place by $\frac{1}{4}$ in (0.6 cm) pieces cut out from hard polyethylene tubing of $\frac{1}{2}$ in (1.3 cm) external diameter (see Fig.A1-5). Thus a $1\frac{1}{2}$ in (3.8 cm) long column containing about 2.3 g of activated charcoal is obtained. Air is sampled at a flow-rate of about 40 l/min through this standard cartridge, and at the end of sampling the cartridge is placed in a well-type NaI scintillation counter, with the air entry end of the cartridge in the downward direction, as most of the radioiodine is collected in the first one inch (2.5 cm) of the column. Counting of the 0.36 MeV gamma photons from $^{131}$I is done by means of a single-channel analyser set. The efficiency of the counting set-up is determined by counting a standard $^{131}$I source in the well.
FIG. A1-6. Details of an assembled brass May Pack (not to scale).
MONITORING OF RADIOIODINE IN AIR USING MAY PACKS

Recently, a modified version of samplers known as May Packs has been tested extensively and put to use for monitoring radioiodine aerosols in effluents. These May Packs are capable of differentiating between various physical and chemical forms of radioiodine.

The May Pack currently in use is a composite sampler consisting of:

- Four circular discs of silver-plated copper screen (25 mm dia., 60 mesh) to remove elemental iodine;
- One millipore membrane filter paper (Gelman type AA, pore size 0.8 µm) to remove particulates;
- Two or three charcoal-impregnated filter papers (Whatman type ACG/B) to remove ionic compounds of iodine (HI);
- Potassium iodide-impregnated activated coconut charcoal (14—18 mesh) to remove methyl iodide or organic iodides in general.

Each screen or filter paper is separated from the other by means of a metallic ring, 8 mm thick, and 1 mm thick Teflon rings, to prevent aerosol leakage at the filters. A small light-duty spring placed after these filters keeps them lightly packed when the May Pack is assembled. Figure A1-6 shows a sketch of the May Pack assembly with all the components and filters in position.

The selectivity and collection efficiency of the components of the May Pack for different forms of radioiodine, i.e. molecular or elemental iodine, HI aerosols, particulate forms of iodine and methyl iodide, were studied in the laboratory by generating these forms of radioiodine aerosols and sampling them with the May Packs. These experiments gave the following results (at flow-rates of 5 l/min, room temperature 30°C, relative humidity 60%):

(a) Radioiodine aerosols of molecular or elemental iodine are deposited on the silver-plated copper screens with an efficiency of not less than 90%;
(b) Methyl iodide aerosols penetrate almost completely the silver-coated copper screens, the millipore filter paper and the ACG/B filter paper, and are adsorbed by the potassium iodide-activated charcoal cartridge with an efficiency of not less than 99%;
(c) Particulate forms of radioiodine aerosols are selectively filtered by the millipore filter with an efficiency of not less than 99%;
(d) HI aerosols are mostly collected both by the silver-coated screens (efficiency 25—35%) and the ACG/B filter paper (60—70%).

The described modified version of the May Pack is excellent for differentiating between molecular forms of radioiodine, organic forms (methyl iodide) and particulate forms, but not very efficient for collecting HI aerosols.
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MEASUREMENT OF CARBON-14 IN GASEOUS EFFLUENTS

H. Riedel, Federal Republic of Germany

Carbon-14 is a pure beta emitter with a maximum energy of 148 keV. In general, the stack monitors will not detect the presence of gaseous $^{14}$C compounds. For this, special sampling and measuring methods are necessary.

SAMPLING METHODS FOR $^{14}$C COMPOUNDS

One method consists of collecting an air sample of 800 l with a high-pressure compressor and then analysing it in the laboratory for its $^{14}$C content of carbon dioxide and hydrocarbons or carbon monoxide.

The sample is conveyed with a flow-rate of 1 l/min to an apparatus where the carbon dioxide is absorbed in sodium hydroxide and the hydrocarbons and carbon monoxide are burnt in a catalytic oven with a CuO catalyst heated to 800°C; thereafter the sample is converted to carbon dioxide, which again is absorbed in sodium hydroxide. To get good results, it is necessary to add as a carrier about 250 ml of methane to the sample. The apparatus is shown in Fig. A1-7. As the sampling period is only a quarter of an hour, the results give only an indication of the release rate within this time. It is also possible to use aluminium-coated plastic bags and fill them in a by-pass with a low-pressure pump.

Another sampling method, which is convenient for collecting the carbon dioxide in the gaseous effluent over a longer time (days or weeks), is to absorb the carbon dioxide in a by-pass to the gaseous effluent in sodium hydroxide. Because of the high content of carbon dioxide in ambient air (0.03 vol.%) it is not necessary to add a carrier gas. For example, at a flow-rate of 1 l/min, over a period of one day, the carbon dioxide in about 1.5 m$^3$ of air can be collected in about 200 ml of 1M sodium hydroxide. Figure A1-8 shows the apparatus used for the sampling. If a lower flow-rate, e.g. 20 ml/min, is used, the sampling period can be extended for a week or for a month.
SAMPLE PREPARATION AND MEASUREMENT

The carbon-14 finally sampled as carbon dioxide in sodium hydroxide solutions is precipitated from these solutions as BaCO₃. For 200 ml of NaOH solution, 200 ml of 1M NH₄Cl solution and 30 ml of 0.5M BaCl₂ solution are added. The BaCO₃ precipitate is then filtered, dried at 120°C, and weighed. Thereafter, the pulverized precipitate is mixed with 0.8 g 'CaboSil' (an amorphic SiO₂ which acts as gelating agent) and 20 ml of scintillator solution (5 g PPO + 0.5 g dimethyl POPOP in 1 l toluene), and treated for 3 min with an ultrasonic vibrator. The suspension is then stable and can be measured in a liquid scintillation spectrometer after 5 hours, allowing for decay of the initially present chemoluminescence. The dependence of the counter efficiency on the amount of BaCO₃ in the sample is shown in Fig. A1-9.

The activity concentration of ¹⁴C in air is then calculated with the formula

\[
C = \frac{k_c \cdot R_n}{2.22 \cdot V \cdot \eta_{ch} \cdot \eta_z}
\]

\[
\eta_{ch} = \frac{E}{A}
\]

where

- \( C \) = ¹⁴C activity concentration
  - (if the activity concentration is to be in Ci/m³, \( k_c = 10^{-12} \)
  - (if in Bq/m³, \( k_c = 3.7 \times 10^{-2} \))
- \( R_n \) = netto pulse rate (counts/min)
- \( V \) = air sample volume (m³)
- \( \eta_z \) = counter efficiency (see Fig.A1-9)
- \( \eta_{ch} \) = chemical yield
- \( E \) = amount of BaCO₃ sample used for the measurement (g)
- \( A \) = amount of barium carbonate precipitated

The detection limit, \( L \), is:

\[
L = \frac{3k_c \sqrt{R_0/t_m}}{2.22 \cdot V \cdot \eta_z \cdot \eta_{ch}}
\]

where

- \( R_0 \) = background pulse rate (counts/min)
- \( t_m \) = measuring time (min)

For a measuring time of 100 min the detection limit is 2 pCi/m³ (7.4 \( \times 10^{-2} \) Bq/m³).
P — pressure flask; D — pressure-reducing valve; A — aerosol filter; K — catalyst (CuO);
G1, 2, 4, 5 — bubblers with CO₂ absorber solution; G3, 6 — bubblers with H₂O;
Z — gas flow meter.
FIG. A1-8. Sampling system for determination of carbon-14 (only CO₂) in the exhaust air with sodium hydroxide.

- A - aerosol filter;
- G₁ - safety flask;
- G₂ - bubbler with frit and NaOH;
- G₃ - safety flask;
- V₁, V₂ - valves;
- P - pump;
- Z - gas flow meter.

FIG. A1-9. Dependence of detection limit on quantity of BaCO₃ in the sample.

MONITORING EQUIPMENT FOR LIQUID EFFLUENTS

I. Gans, Federal Republic of Germany

FLOW OF LIQUID EFFLUENT STREAM

Liquid effluents that are possibly contaminated by radioactive substances may only be discharged in batches from discharge tanks designed for this purpose.
According to administrative orders, discharge monitoring involves the following five steps, as shown in the flow diagram (Fig.A1-10):

1. Sampling and measurement before discharge.
2. Sampling for storage.
3. Composite sampling for specific radionuclide analysis.
4. Continuous gamma counting in the discharge pipe from the discharge tank and in the cooling-water outlet.
5. Continuous sampling in the cooling-water outlet and inlet and analysis of specific radionuclides in composite samples.

The two last monitoring steps are intended to detect unplanned releases.
SAMPLING TECHNIQUES

Sampling from discharge tanks

The effluents in the discharge tanks are free from suspended material. The water volume (50—60 m³) is homogenized by pumping in a closed circuit or by sparkling with pressurized air. Samples are taken after appropriate flushing of the pipes near the tanks. Period and rate of pumping as well as the time for pipe flushing are optimized before starting reactor operation in order to provide representative samples.

For measurement before discharge a sample volume of 1 litre is needed. This sample is stored for one year in a polyethylene bottle. Additional samples are needed for the composition of samples.

Composite samples

An analysis of specific radionuclides is performed on composite samples from all discharges of one week, one month or three months, respectively. It has been shown to be useful to discharge the effluents in batches of constant volume so that constant sample volumes can be used for mixing samples.

Samples of cooling water

Samples of cooling water are taken continuously over periods of one day from pipes or from the discharge channel. Volumes collected during one day are typically from a few litres up to 1 m³.

A tank of 1 m³ is situated near the end of the cooling-water discharge pipe. Before the daily sample of 1 litre is taken, the contents of the tank are homogenized by an automatic agitator. After 30 days storage the samples of one month are mixed and analysed.

MEASURING TECHNIQUES

Gross gamma measurement

Before discharging a batch of liquid effluents it has to be proven that a concentration of $5 \times 10^{-4}$ Ci/m³ ($1.9 \times 10^7$ Bq/m³) is not exceeded. The measurement is performed as an integral gamma measurement for energies above 100 keV. The activity concentration is given in comparison with a $^{137}$Cs solution ($^{137}$Cs equivalent).
### TABLE A1-III. RADIONUCLIDES IN LIQUID EFFLUENTS AND REQUIRED MINIMUM DETECTION LIMITS

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Minimum detection limit (Ci/m³)</th>
<th>Minimum detection limit (Bq/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>$1 \times 10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Cr-51</td>
<td>$5 \times 10^{-6}$</td>
<td>$1.9 \times 10^{5}$</td>
</tr>
<tr>
<td>Mn-54</td>
<td>$1 \times 10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Fe-59</td>
<td>$2 \times 10^{-6}$</td>
<td>$7.4 \times 10^{4}$</td>
</tr>
<tr>
<td>Co-57</td>
<td>$3 \times 10^{-7}$</td>
<td>$1.1 \times 10^{4}$</td>
</tr>
<tr>
<td>Co-58</td>
<td>$8 \times 10^{-7}$</td>
<td>$3.0 \times 10^{4}$</td>
</tr>
<tr>
<td>Co-60</td>
<td>$1 \times 10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
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<tr>
<td>Zn-65</td>
<td>$2 \times 10^{-6}$</td>
<td>$7.4 \times 10^{4}$</td>
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<tr>
<td>Sr-89</td>
<td>$2 \times 10^{-8}$</td>
<td>$7.4 \times 10^{2}$</td>
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<tr>
<td>Sr-90</td>
<td>$2 \times 10^{-8}$</td>
<td>$7.4 \times 10^{2}$</td>
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<tr>
<td>Zr-95</td>
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<td>Nb-95</td>
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<td>Ru-106</td>
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<td>Ag-110m</td>
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<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Sb-124</td>
<td>$2 \times 10^{-6}$</td>
<td>$7.4 \times 10^{4}$</td>
</tr>
<tr>
<td>Sb-125</td>
<td>$2 \times 10^{-6}$</td>
<td>$7.4 \times 10^{4}$</td>
</tr>
<tr>
<td>I-131</td>
<td>$7 \times 10^{-7}$</td>
<td>$2.6 \times 10^{4}$</td>
</tr>
<tr>
<td>Cs-134</td>
<td>$8 \times 10^{-7}$</td>
<td>$3.0 \times 10^{4}$</td>
</tr>
<tr>
<td>Cs-137</td>
<td>$8 \times 10^{-7}$</td>
<td>$3.0 \times 10^{4}$</td>
</tr>
<tr>
<td>Ba-140</td>
<td>$3 \times 10^{-6}$</td>
<td>$1.1 \times 10^{5}$</td>
</tr>
<tr>
<td>La-140</td>
<td>$7 \times 10^{-7}$</td>
<td>$2.6 \times 10^{4}$</td>
</tr>
<tr>
<td>Ce-141</td>
<td>$7 \times 10^{-7}$</td>
<td>$2.6 \times 10^{4}$</td>
</tr>
<tr>
<td>Ce-144</td>
<td>$3 \times 10^{-6}$</td>
<td>$1.1 \times 10^{5}$</td>
</tr>
<tr>
<td>α-emitters</td>
<td>$5 \times 10^{-9}$</td>
<td>$1.9 \times 10^{2}$</td>
</tr>
</tbody>
</table>
A typical equipment used is a 3 in X 3 in (7.6 cm X 7.6 cm) NaI detector in lead shielding, combined with a one-channel analyser. The sample is measured in Marinelli beakers or in bottles. The requested minimum range of measurement is $5 \times 10^{-5}$ to $5 \times 10^{-3}$ Ci/m$^3$ (1.9 x $10^6$ to 1.9 x $10^8$ Bq/m$^3$) $^{137}$Cs equivalent.

**Specific radionuclides**

Analyses for specific radionuclides are performed by using standard procedures (gamma spectrometry, radiochemical separation and low-level beta counting, liquid scintillation counting, large-area flow counting for alpha emitters).

Table A1-III shows the radionuclides to be determined. The minimum detection limits have to be reached in every determination. The detection limits for gamma emitters can be reached by using a Ge(Li) detector of, for instance, 100 cm$^3$ and 18% efficiency and measuring times of 2 hours. Analysis of pure beta emitters is mostly performed by institutions outside the nuclear power facilities.

**IN-SITU MEASUREMENTS**

Continuous gamma counting is performed by using 3 in X 3 in (7.6 cm X 7.6 cm) NaI detectors. The required minimum detection limit for monitoring of the cooling water is $10^{-7}$ Ci/m$^3$ (3.7 x $10^3$ Bq/m$^3$); for the discharge pipe it is $5 \times 10^{-6}$ Ci/m$^3$ (1.9 x $10^5$ Bq/m$^3$).

The measurements are recorded in the control room. If thresholds are exceeded or if the equipment fails, optical and acoustical signals are given.

**MONITORING OF GASEOUS EFFLUENTS IN ONTARIO HYDRO**

M.J. Kabat, Canada

**RECENT AND FUTURE DEVELOPMENTS**

**Particulate and radioiodine monitoring**

*Selective radioiodine species sampler*

A method for generating hypoiodous acid was developed for the purpose of ventilation filter testing. A selective iodine species sampler was also developed.

---

and used for the selective sampling of iodine species in Candu power station areas. It is now possible to perform an analysis of iodine species in gaseous effluents when a significant iodine release occurs (>1% of DRL).  

Radioactive incinerator effluent monitoring

A stack monitoring system was developed for a radioactive incinerator. The hot effluent sample is collected (at 230°C) on a particulate (glass fibre) filter and iodine (silver zeolite) collector, which are installed in a common holder and viewed by a cooled gamma scintillation probe. The monitor measures gross gamma count-rate and its alarm level is set to the most restrictive component — $^{131}$I. Radiometric evaluation of both collectors for compliance purposes is performed in the laboratory on a routine basis. A similar monitor, but without the detector cooling system, is installed on the radioactive incinerator active building ventilation exhaust duct.

---

1 The HOI generator was also used to investigate the deposition rate of HOI relative to CH$_3$I and it was found to be an order of magnitude higher.

---

### TABLE A1-IV. GAMMA Ci · MeV (Bq · MeV) VALUES OF NOBLE GAS RADIOISOTOPES IN GASEOUS EFFLUENTS

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Decay half-life</th>
<th>$\bar{E}_\gamma$ (Ci · MeV/disintegr.)</th>
<th>$\bar{E}_\gamma$ (Bq · MeV/disintegr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ar-41</td>
<td>108 min</td>
<td>1.29</td>
<td>4.77 $\times 10^{10}$</td>
</tr>
<tr>
<td>Kr-85m</td>
<td>4.4 h</td>
<td>0.156</td>
<td>0.58 $\times 10^{10}$</td>
</tr>
<tr>
<td>Kr-87</td>
<td>76 min</td>
<td>0.775</td>
<td>2.87 $\times 10^{10}$</td>
</tr>
<tr>
<td>Kr-88 + Rb-88</td>
<td>2.8 h</td>
<td>2.03 + 0.692</td>
<td>(7.51 + 2.56) $\times 10^{10}$</td>
</tr>
<tr>
<td>Xe-133</td>
<td>5.27 d</td>
<td>0.030</td>
<td>1.11 $\times 10^{10}$</td>
</tr>
<tr>
<td>Xe-133m</td>
<td>2.26 d</td>
<td>0.023</td>
<td>0.085 $\times 10^{10}$</td>
</tr>
<tr>
<td>Xe-135</td>
<td>9.2 h</td>
<td>0.245</td>
<td>0.91 $\times 10^{10}$</td>
</tr>
<tr>
<td>Xe-135m</td>
<td>15.6 min</td>
<td>0.421</td>
<td>1.56 $\times 10^{10}$</td>
</tr>
<tr>
<td>Xe-138 + Cs-138</td>
<td>17 min</td>
<td>1.053 + 2.387</td>
<td>(3.90 + 8.83) $\times 10^{10}$</td>
</tr>
</tbody>
</table>
Particulate and iodine monitoring in power station effluents

A particulate + radioiodine control monitor is being developed in our laboratory. A combination of a commercial single-channel analyser with a microprocessor, programmed for the required functions, is being tested for this purpose.

Noble gas monitoring

*Gamma Ci • MeV (Bq • MeV) monitoring of noble gas effluents*

It is evident from the theoretical analysis [1] that using a semi-infinite cloud approximation, the gamma dose-rate limits the factor for concentration time.
integral of nuclear power station noble gas effluents. The external dose rate \( R \) (rad/s or Gy/s) from a semi-infinite cloud is directly proportional to both the noble gas isotope concentration \( C_1 (\text{Ci/m}^3) \) or \( C_2 (\text{Bq/m}^3) \) and the integrated gamma energy per disintegration \( \bar{E}_\gamma \), as follows:

\[
R = 0.25 \times \bar{E}_\gamma \times C_1 \quad \text{(rad/s)}
\]

\[
= 67 \times 10^{-15} \times \bar{E}_\gamma \times C_2 \quad \text{(Gy/s)}
\]

The gamma Ci · MeV (Bq · MeV) values for the most common noble gas isotopes in nuclear power station effluents calculated from the data in Oak Ridge Decaygam [2] are listed in Table A1-IV.

The gamma Ci · MeV (Bq · MeV) content of the noble gas in the effluent can be monitored in two ways:

(a) Using an energy-corrected gamma radiation detector with detection efficiency directly proportional to energy of detected gamma radiation. The pulse rate from this detector is proportional to the ‘gamma Ci · MeV (Bq · MeV) concentration’ of the noble gas mixture in the detection chamber, and integrated pulses are proportional to the total noble gas gamma Ci · MeV (Bq · MeV) release.

(b) Using a scintillation detector whose output pulse is proportional to the detected gamma energy. The detector current is then directly proportional to the gamma Ci · MeV (Bq · MeV) concentration of noble gases in the detection chamber.

Both the above methods require that only the gamma component of the noble gas radiation is monitored and that constant effluent flow is maintained through the monitoring period.

Gamma energy response of a GM detector

The gamma energy response of the Amperex type 912 NB3 GM detector, installed in the noble gas monitors at present in use, was measured using a set of NBS primary gamma standards covering the energy range of 60 keV – 1.3 MeV (\(^{241}\text{Am}, ^{109}\text{Cd}, ^{57}\text{Co}, ^{203}\text{Hg}, ^{133}\text{Ba}, ^{137}\text{Cs}, ^{54}\text{Mn}, ^{60}\text{Co})\). The energy response was measured with the lead shielding originally supplied on the GM detector, and with the shielding removed. Then the energy response correcting effect of several materials was tested in order to optimize the detector for noble-gas Ci · MeV (Bq · MeV) monitoring. The optimum energy response was achieved using a combination of 6 mm plexiglass, 2 mm of copper and 1 mm of steel shielding around the GM tube.
TABLE A1-V. TYPICAL COMPOSITION OF CANDU STATION NOBLE GAS EFFLUENTS

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Concentration (μCi/m³)</th>
<th>Daily release (Ci·MeV/d)</th>
<th>Per cent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Bq/m³)</td>
<td>(Bq·MeV/d)</td>
<td></td>
</tr>
<tr>
<td>Kr-85m</td>
<td>0.08</td>
<td>0.03</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>0.3 × 10⁴</td>
<td>0.11 × 10¹⁰</td>
<td></td>
</tr>
<tr>
<td>Kr-87</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Kr-88</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Xe-133</td>
<td>64.41</td>
<td>0.51</td>
<td>42.36</td>
</tr>
<tr>
<td></td>
<td>2.38 × 10⁶</td>
<td>1.89 × 10¹⁰</td>
<td></td>
</tr>
<tr>
<td>Xe-133m</td>
<td>0.14</td>
<td>0.01</td>
<td>0.72</td>
</tr>
<tr>
<td></td>
<td>0.52 × 10⁴</td>
<td>0.04 × 10¹⁰</td>
<td></td>
</tr>
<tr>
<td>Xe-135</td>
<td>1.93</td>
<td>0.12</td>
<td>10.36</td>
</tr>
<tr>
<td></td>
<td>7.14 × 10⁴</td>
<td>0.44 × 10¹⁰</td>
<td></td>
</tr>
<tr>
<td>Ar-41</td>
<td>1.64</td>
<td>0.56</td>
<td>46.28</td>
</tr>
<tr>
<td></td>
<td>6.07 × 10⁴</td>
<td>2.07 × 10¹⁰</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.23</strong></td>
<td><strong>4.55 × 10¹⁰</strong></td>
<td>(0.08% of daily DRL)</td>
</tr>
</tbody>
</table>

The noble gas detector and flow chamber assembly were calibrated using gaseous ⁴¹Ar and ¹³³Xe samples.

Figure A1-11 shows the Ci·MeV (Bq·MeV) response curves, measured with the above NBS sources. It also shows that the counts per Ci·MeV (Bq·MeV) for ¹³³Xe and ⁴¹Ar (two major radionuclides in the Candu power station effluents) with the above composite shielding are almost identical. In the gamma energy region of approximately 0.12 MeV the detector Ci·MeV (Bq·MeV) response is 50% greater than that measured at ¹³³Xe and ⁴¹Ar energies.

Application of TLDs for noble gas emergency monitoring

The noble gas monitors at present in use have the following disadvantages:

(a) Limited upper monitoring range (long GM-detector dead time);
(b) Unsatisfactory energy response for Ci·MeV (Bq·MeV) measurement;
(c) No accumulative sample is available for accurate laboratory evaluation of noble gas releases;
(d) Information on released noble gas radioisotopes may be lost from power loss or accidental resetting of the scaler.
The applicability of TLDs for noble gas monitoring was investigated. Their gamma energy response characteristics and wide detection range indicated that they could be employed as a back-up to the on-line stack effluent noble gas monitors, particularly for emergency purposes.

An experimental set-up was installed in the Pickering NGS ventilation stack. Both the noble gas gamma radiation in the stack and external gamma background were detected coincidently with two sets of TLDs and periodically evaluated. The noble gas effluent was coincidently measured with a gamma spectrometer and the Ci·MeV totalized for each TLD evaluation period. It was concluded that TLDs in such an arrangement can measure noble gas release levels of <1\% of emission limits with good accuracy.

FIG. A1-12. Yield of $^{133}$Xe and $^{135}$Xe from decay of radioiodine precursors.
Gamma spectrometric analysis of noble gas effluent samples

A method was developed for gamma spectrometric analysis of stack effluent samples employing long-period effluent sample counting with a shielded Ge(Li) detector. Corrections for decay of short-lived radionuclides during the long counting periods are made in computing the initial nuclide concentrations. The high sensitivity of this method allows accurate measurement of radionuclide concentrations at levels significantly below 0.01% of the emission limits. A typical composition of noble gas radioisotopes in Candu station effluents is shown in Table A1-V.

Generation of xenon radioisotopes

Xenon isotopes $^{133}$Xe + $^{135}$Xe are noble gas fission products typically found in Candu power station gaseous effluents.

A method was developed for generating a mixture of xenons for noble gas effluent monitor calibration. A mixture of radioiodine ($^{131}$I + $^{133}$I + $^{135}$I) is absorbed from the primary coolant ($D_2O$) in a small anion exchange column. The column is sealed and $^{133}$I, $^{135}$I, $^{133}$Xe and $^{135}$Xe are quantitatively evaluated with a calibrated gamma spectrum analyser. The column is then kept sealed for a period, determined from the graph in Fig. A1-12, to generate $^{133}$Xe and $^{135}$Xe in the required ratio.

The graph was calculated from the equation:

$$A_2 = A_1 \times \frac{e^{-\lambda_1 t} - e^{-\lambda_2 t}}{\lambda_2 - \lambda_1}$$

where:

- $A_1$ = activity of iodine isotope
- $\lambda_1$ = decay constant of iodine isotope
- $A_2$ = activity of xenon isotope (decay product)
- $\lambda_2$ = decay constant of xenon isotope

The activities are usually of the order of microcuries, i.e. tens of kilobecquerels, and the decay constants are usually in reciprocal hours to correspond with the time, t, in hours.

Noble gas effluent monitor with plastic scintillation probe

A theoretical analysis has been performed to investigate the application of plastic scintillators for noble gas Ci • MeV (Bq • MeV) monitoring. From the
manufacturer's data on the NE 102 plastic scintillator, the energy correction effect of different materials was calculated. The results indicate that the fraction of the initial gamma energy absorbed in the plastic scintillator is almost constant (within ±15%) within the gamma-energy range of 0.08 – 1.3 MeV when 20 mm of graphite is applied as the energy correction shielding.

Experimental work has been initiated to confirm the above results.

Tritium monitoring in the radioactive incinerator effluents

A special tritium collector was developed for collecting tritium oxide from the high-temperature incinerator effluent sampling line downstream of the combined particulate and iodine collectors. The sample is cooled to 15°C and carried to a water bubbler collecting both the tritium oxide vapour and condensed liquid. The collected tritium oxide is then measured with a liquid scintillation counter.

Quality assurance

Sampling line testing

A test for the representativeness of effluent sampling is performed by injecting freon into the ventilation duct inlet, evaluating its concentration profile across the ventilation duct upstream of an effluent sampling nozzle, and measuring its concentration in the sampling line.

The ambient air in-leak rate is evaluated by a pressure decay method.

The sampling efficiency of the particulate collector system is tested by injecting poly-dispersed DOP into the sampling line and comparing its concentration measured upstream and downstream of the filter holder.

The efficiency of the iodine sampling cartridge and its gaskets is tested in a similar way by injecting ¹³¹I-tagged methyl iodide into the sample stream and measuring its concentration downstream of the charcoal cartridge.

Effluent monitor testing

Gaseous effluent monitor testing and calibration procedures recommended for Ontario Hydro's nuclear power stations are described by Kabat [3]. Detailed procedures are given for setting of operational parameters and monitor calibration. Routine checks, field operation and sample evaluation procedures are also described.
CONCLUSION

The development of a new gaseous effluent monitoring system for Ontario Hydro nuclear facilities is based on defined control, compliance and emergency monitoring programmes.

Performance standards are being developed for important system parameters. The current system concept includes:

(a) Optimized sample line design;
(b) On-line gross gamma monitor with coincident detection of both particulate and iodine collectors with a NaI detector;
(c) On-line noble gas monitor with plastic scintillator for measuring the noble gas Ci MeV (Bq MeV) release rate and integrated release. TLD back-up for emergency evaluation;
(d) Silica gel samplers for tritium compliance measurement.

Quality assurance programmes are an integral part of the system design. Improvement objectives have been defined and form the basis for future development programmes.

REFERENCES

Annex 2

EXAMPLES OF MONITORING SYSTEMS FOR RADIOACTIVE AIRBORNE AND LIQUID RELEASES FROM NUCLEAR FACILITIES

MONITORING OF THE DISCHARGE OF RADIOACTIVE MATERIALS IN GASEOUS EFFLUENTS AT THE STACK OF NUCLEAR POWER PLANTS WITH LIGHT-WATER-COOLED REACTORS

J. Schwibach, Federal Republic of Germany

1. FUNCTIONS OF DISCHARGE MONITORING AT THE STACK

Monitoring of the discharge of radioactive materials in gaseous effluents at the stack of nuclear power plants is done with the following aims:

(a) Determination of the activity of radioactive materials discharged into the atmosphere during regular operation in accordance with the specifications of the licensing conditions; the measurements have to be carried out in such a way that, if certain levels of activity discharge rate are reached, automatic safety measures can be initiated.

(b) Possibility of evaluating the environmental exposure and estimating the potential annual population exposure.

The requirements of sampling and measuring procedures specified below represent a minimum for the monitoring of the discharge of radioactive materials in gaseous effluents at the stack during regular operation.

2. SAMPLING REQUIREMENTS

Sampling should be representative and shall be carried out according to the current state of technology.

The air flow through the stack shall be measured and registered continuously. Furthermore, if enrichment procedures are used, it must be possible to determine the volume flow through the sampling pipe.
TABLE A2-I. RADIONUCLIDES TO BE ACCOUNTED FOR IN THE MEASUREMENT OF THE NUCLIDE COMPOSITION OF RADIOACTIVE GASES

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe-133</td>
<td>5.3 d</td>
</tr>
<tr>
<td>Xe-135</td>
<td>9.14 h</td>
</tr>
<tr>
<td>Xe-135m</td>
<td>15.7 min</td>
</tr>
<tr>
<td>Xe-137</td>
<td>3.85 min</td>
</tr>
<tr>
<td>Xe-138</td>
<td>14.2 min</td>
</tr>
<tr>
<td>Kr-85m</td>
<td>4.48 h</td>
</tr>
<tr>
<td>Kr-87</td>
<td>76.4 min</td>
</tr>
<tr>
<td>Kr-88</td>
<td>2.8 h</td>
</tr>
<tr>
<td>Kr-89</td>
<td>3.16 min</td>
</tr>
<tr>
<td>Ar-41</td>
<td>1.83 h</td>
</tr>
</tbody>
</table>

3. REQUIREMENTS OF MEASURING TECHNIQUES

In principle, all discharges of radioactive materials into the atmosphere shall be monitored by continuous measurement of radionuclides or groups of radionuclides. To evaluate the radiological effects of released radionuclide mixtures, it is necessary to balance the single radionuclides. This balancing shall be performed mainly for samples which have been taken proportionally to the volume. For the purpose of balancing certain radionuclide groups, random sampling with subsequent measurement will be sufficient if the assumptions regarding the composition of the radionuclide mixture are conservative for estimating the radiation exposure.

For monitoring the different radionuclides or radionuclide mixtures in the gaseous effluent at the stack, the measurements mentioned below shall be carried out. The upper detection limits of the continuous measuring techniques should be such that the licensed discharge rates can be detected.

3.1. Measurement of radioactive gases

(a) The discharge rate of radioactive gases in the effluent at the stack shall be evaluated by continuous measurement of the activity concentration in a bypass providing a lower detection limit of $2 \times 10^{-7}$ Ci/m$^3$ ($7.4 \times 10^3$ Bq/m$^3$)
<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Type of decay</th>
<th>Detection limit$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Ci/m$^3$) (Bq/m$^3$)</td>
</tr>
<tr>
<td>Cr-51</td>
<td>27.8 d</td>
<td>K, $\gamma$</td>
<td>$4 \times 10^{-13}$ $1.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>Mn-54</td>
<td>314 d</td>
<td>K, $\gamma$</td>
<td>$5 \times 10^{-14}$ $1.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>Fe-59</td>
<td>45.6 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$8 \times 10^{-14}$ $3.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>Co-57</td>
<td>270 d</td>
<td>K, $\gamma$</td>
<td>$4 \times 10^{-14}$ $1.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Co-58</td>
<td>71.3 d</td>
<td>K, $\beta^-$, $\gamma$</td>
<td>$6 \times 10^{-14}$ $2.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Co-60</td>
<td>5.27 a</td>
<td>$\beta^-$, $\gamma$</td>
<td>$9 \times 10^{-14}$ $3.3 \times 10^{-3}$</td>
</tr>
<tr>
<td>Sr-89</td>
<td>52.7 d</td>
<td>$\beta^-$</td>
<td>$1 \times 10^{-14}$ $3.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Sr-90</td>
<td>28 a</td>
<td>$\beta^-$</td>
<td>$1 \times 10^{-14}$ $3.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Zr-95</td>
<td>65.5 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$9 \times 10^{-14}$ $3.3 \times 10^{-3}$</td>
</tr>
<tr>
<td>Nb-95</td>
<td>35 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$6 \times 10^{-14}$ $2.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Ru-103</td>
<td>40 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$4 \times 10^{-14}$ $1.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Ru-106</td>
<td>368 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$4 \times 10^{-13}$ $1.5 \times 10^{-2}$</td>
</tr>
<tr>
<td>Ag-110m</td>
<td>255 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$5 \times 10^{-14}$ $1.9 \times 10^{-3}$</td>
</tr>
<tr>
<td>Sb-124</td>
<td>60.4 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$8 \times 10^{-14}$ $3.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>Sb-125</td>
<td>2.71 a</td>
<td>$\beta^-$, $\gamma$</td>
<td>$8 \times 10^{-14}$ $3.0 \times 10^{-3}$</td>
</tr>
<tr>
<td>I-131</td>
<td>8.05 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$4 \times 10^{-14}$ $1.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Cs-134</td>
<td>2.05 a</td>
<td>$\beta^-$, $\gamma$</td>
<td>$6 \times 10^{-14}$ $2.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Cs-137</td>
<td>30 a</td>
<td>$\beta^-$, $\gamma$</td>
<td>$6 \times 10^{-14}$ $2.2 \times 10^{-3}$</td>
</tr>
<tr>
<td>Ba-140</td>
<td>12.8 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$3 \times 10^{-13}$ $1.1 \times 10^{-2}$</td>
</tr>
<tr>
<td>La-140</td>
<td>40.2 h</td>
<td>$\beta^-$, $\gamma$</td>
<td>$4 \times 10^{-14}$ $1.5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Ce-141</td>
<td>32.5 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$2 \times 10^{-14}$ $7.4 \times 10^{-4}$</td>
</tr>
<tr>
<td>Ce-144</td>
<td>283 d</td>
<td>$\beta^-$, $\gamma$</td>
<td>$3 \times 10^{-13}$ $1.1 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

$^a$ These detection limits (with the exception of the strontium isotopes) are reached using a measuring time of 100 min and an air-flow of 250 m$^3$/week (filter diameter 5 cm), taking as a basis a 3σ confidence interval. These values apply to a Ge(Li) detector with a lead shielding of 5 cm, having a relative efficiency of 5.5% and a resolution of 2.0 keV for the 1332 keV line of Co-60.
related to $^{135}$Xe. The measurement shall not be interfered with by aerosol contamination.

(b) For the radionuclides mentioned in Table A2—I, the radionuclide composition of the radioactive gases shall be determined using a lower detection limit of $10^{-8}$ Ci/m$^3$ ($3.7 \times 10^2$ Bq/m$^3$). Balancing has to be performed either by continuous sampling and measurement using gamma spectrometry or by weekly sampling of a representative sample from the gaseous effluents at the stack, with subsequent measurements using gamma spectrometry.

(c) Under special operational conditions, which should be specified in detail, or in case of exceeding certain specified limits of the continuous gas measuring installation, or of the continuous aerosol measuring installation, or of the continuous iodine measuring installation, the determination of the radionuclide composition mentioned in the previous paragraph must be carried out immediately.

3.2. Measurement of radioactive aerosols

(a) The discharge rate of radioactive aerosols in the gaseous effluents at the stack shall be monitored continuously by an enrichment procedure.

(b) For balancing, radioactive aerosols in the effluents at the stack shall be gathered by continuous sampling for the period of usually one week on a filter with a sampling efficiency of at least 90%.

(c) Within one week after sampling, a determination of single radionuclides (except for $^{131}$I) by gamma spectrometry shall be carried out, balancing the nuclides enlisted in Table A2—II with the appropriate detection limits. If necessary, a correction of the radioactive decay related to the middle of the sampling period should be performed.

(d) Strontium-89 and strontium-90 shall be balanced quarterly by radiochemical analyses of the sample consisting of the aerosol filters exposed during the appropriate period.

(e) The alpha activity discharged in the gaseous effluents at the stack shall be balanced by measuring a sample taken during a quarter of a year. For single radionuclides a lower detection limit of $4 \times 10^{-14}$ Ci/m$^3$ ($1.5 \times 10^{-3}$ Bq/m$^3$) shall be reached.$^1$

(f) In the case of special operational conditions, which shall be specified in detail, or in the case of exceeding certain specified limits of the continuous gas measuring installation, or of the continuous aerosol measuring installation, or of the continuous iodine measuring installation, the aerosol filter has to be exchanged and analysed immediately according to para. 3.2 (c).

$^1$ For the determination of the amount of $^{89}$Sr and $^{90}$Sr, and the alpha-emitting nuclides, the same sample may be used if first cold ashing of the sample has been performed for alpha measurement and subsequently the amount of strontium is determined.
3.3. Measurement of radioactive iodine

(a) The discharge rate of radioactive iodine isotopes in the effluents at the stack shall be controlled continuously by an enrichment procedure. The measurement may not be interfered with by aerosol contamination.

(b) For the purpose of balancing, gaseous radioactive iodine isotopes in the effluents at the stack shall be sampled during the period of usually one week by continuous sampling on an iodine filter. The iodine filter shall also retain organic iodine compounds (such as methyl iodide) with a sampling efficiency of at least 90%. For the sampling of aerosols, an aerosol filter shall be attached before the iodine filter. This shall be analysed separately for iodine.

(c) Within one day after sampling, a determination of single radionuclides by gamma spectrometry has to be carried out. Iodine-131 shall be balanced with the lower detection limit given in Table A2-II. The measurement of other iodine isotopes (e.g. 133I and 135I) is only for control.

(d) In the case of special operational conditions, which shall be specified in detail, or in the case of exceeding certain specified limits of the continuous gas measuring installation, or of the continuous aerosol measuring installation, or of the continuous iodine measuring installation, the iodine filter shall be exchanged and analysed immediately according to para. 3.3. (c).

3.4. Measurement of tritium

(a) Tritium shall be detected by continuous sampling of water vapour in the effluents at the stack.

(b) Measurements of a condensed mixed sample shall be performed quarterly.

(c) A lower detection limit of $10^{-8} \text{Ci/m}^3$ ($3.7 \times 10^2 \text{Bq/m}^3$) related to the gaseous effluents at the stack shall be provided.

MONITORING OF THE RELEASE OF RADIOACTIVE SUBSTANCES FROM NUCLEAR FACILITIES INTO SURFACE WATERS

Prepared by the Study Group on Radioactive Contamination of Surface Water of the “Länderarbeitsgemeinschaft Wasser”

J. Schwibach, Federal Republic of Germany

1. CONDITIONS FOR DISCHARGE

(1.1) Notwithstanding established limits and protection regulations, the licensee has to keep the release of radioactive substances as low as possible by
### TABLE A2–III. PHYSICAL DATA AND DETECTION LIMITS OF THE RADIONUCLIDES TO BE TAKEN INTO ACCOUNT FOR DETERMINING TOTAL ACTIVITY

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Decay</th>
<th>$E^a$ (MeV)</th>
<th>Detection limit (Ci/m$^3$)</th>
<th>Detection limit (Bq/m$^3$)</th>
<th>MPC$_w$ (Ci/m$^3$)</th>
<th>MPC$_w$ (Bq/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>12.26 a</td>
<td>α, β</td>
<td>1 $\times$ 10$^{-6}$</td>
<td>3.7 $\times$ 10$^4$</td>
<td>3 $\times$ 10$^{-2}$</td>
<td>1.1 $\times$ 10$^9$</td>
<td></td>
</tr>
<tr>
<td>C-51</td>
<td>27.8 d</td>
<td>α, β</td>
<td>5 $\times$ 10$^{-6}$</td>
<td>1.9 $\times$ 10$^5$</td>
<td>2 $\times$ 10$^{-2}$</td>
<td>7.4 $\times$ 10$^6$</td>
<td></td>
</tr>
<tr>
<td>Mn-54</td>
<td>314 d</td>
<td>α, β</td>
<td>1 $\times$ 10$^{-6}$</td>
<td>3.7 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Fe-59</td>
<td>45.6 d</td>
<td>α, β</td>
<td>3 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>5 $\times$ 10$^{-4}$</td>
<td>1.9 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Co-57</td>
<td>270 d</td>
<td>α, β</td>
<td>1 $\times$ 10$^{-6}$</td>
<td>3.7 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Co-58</td>
<td>71.3 d</td>
<td>α, β</td>
<td>3 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>4 $\times$ 10$^{-3}$</td>
<td>1.5 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Co-60</td>
<td>5.27 a</td>
<td>α, β</td>
<td>1 $\times$ 10$^{-6}$</td>
<td>3.7 $\times$ 10$^4$</td>
<td>3 $\times$ 10$^{-4}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Zn-65</td>
<td>245 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>3 $\times$ 10$^{-4}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Sr-89</td>
<td>50.5 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>7 $\times$ 10$^{-4}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Sr-90</td>
<td>28 d</td>
<td>γ</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Zr-95</td>
<td>65.5 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>3 $\times$ 10$^{-4}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Nb-95</td>
<td>35 d</td>
<td>α, β</td>
<td>3 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ru-103</td>
<td>40 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>8 $\times$ 10$^{-4}$</td>
<td>3.0 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ru-106</td>
<td>368 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ag-110m</td>
<td>255 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>6 $\times$ 10$^{-4}$</td>
<td>2.2 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ir-110m</td>
<td>60.4 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ir-110m</td>
<td>2.6 a</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ir-111m</td>
<td>8.05 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ir-111m</td>
<td>2.6 a</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-3}$</td>
<td>3.7 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ir-112m</td>
<td>30 a</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>2 $\times$ 10$^{-4}$</td>
<td>7.4 $\times$ 10$^6$</td>
<td></td>
</tr>
<tr>
<td>Ir-112m</td>
<td>12.8 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>2 $\times$ 10$^{-4}$</td>
<td>7.4 $\times$ 10$^6$</td>
<td></td>
</tr>
<tr>
<td>Ir-113m</td>
<td>40.2 h</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>2 $\times$ 10$^{-4}$</td>
<td>7.4 $\times$ 10$^6$</td>
<td></td>
</tr>
<tr>
<td>Ir-114m</td>
<td>32.5 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>9 $\times$ 10$^{-4}$</td>
<td>3.3 $\times$ 10$^7$</td>
<td></td>
</tr>
<tr>
<td>Ir-115m</td>
<td>284 d</td>
<td>α, β</td>
<td>2 $\times$ 10$^{-6}$</td>
<td>7.4 $\times$ 10$^4$</td>
<td>1 $\times$ 10$^{-4}$</td>
<td>3.7 $\times$ 10$^6$</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Energy used for evaluation.

Note: The radionuclides given in the table are those that were determined at least once in liquid effluents from an operating nuclear power station in the Federal Republic of Germany during a series of investigations at the Institute of Water, Air and Soil Hygiene of the Federal Health Office over several years. If further radionuclides are found, for these, too, detection limits have to be determined and taken into account.

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appropriate technical equipment and by appropriately established operation conditions in order to restrict possible radiation effects to a minimum. The licensing authority reserves the right to request additional measures for reducing the releases of radioactive substances, taking the most recent state of technology into account.

(1.2) All liquid wastes that are or may be radioactively contaminated during normal power plant operation have to be transferred to collecting tanks by the waste water system designed for this purpose.

Non-radioactive liquid wastes from beyond the controlled and monitored area of the nuclear power station must not be conveyed to this system.

The waste system has to be designed in such a way as to allow the separate collection of liquid wastes of different radionuclide content and of different chemical quality in order to assure extensive decontamination.

(1.3) Radioactive effluents may only be discharged from discharge tanks. Suspended materials have to be removed by appropriate measures before discharge. Effluents may not be drained off by gravity, but have to be pumped out. Conduits have to be designed in such a way that circumvention of discharge tanks is excluded. While discharging effluents, water must not be conveyed to the discharge tank.

(1.4) Before discharge, a sample that is representative of the total volume of the discharge tank has to be taken. From this sample, a volume of 1 litre has to be used for a measurement, in order to decide on the permissibility of the discharge (see 2.1), and has to be stored as evidence for a period of one year. From other parts of the sample, weekly, monthly and quarterly aliquot samples have to be composed (see 2.2).

(1.5) Effluents may only be pumped out from discharge tanks if a gross gamma-activity measurement has proved that the radionuclide concentration of the water in the discharge tank does not exceed $5 \times 10^{-4} \text{Ci/m}^3$ ($1.9 \times 10^7 \text{Bq/m}^3$), compared with a $^{137}\text{Cs}$ equivalent (see 2.1). Moreover, it has to be assured that the activity discharge permitted for certain periods of time is not exceeded.

(1.6) The effluents contained in the discharge tank may only be pumped out after written permission has been given by the liable plant staff member or his substitute who has been named to the authority concerned.

The permission and the actual discharge of the effluent have to be recorded in the operation journal (result of the measurement before discharge, time and volume of discharge, names of liable person and of executing person).

(1.7) The discharge of effluents from the discharge tank has to be exhibited and recorded in the control room.

(1.8) A continuously operating gamma-sensitive monitoring device has to be installed in the discharge line, which terminates the discharge automatically in case
(a) the concentration of radioactive substances in the water exceeds $5 \times 10^{-4} \text{Ci/m}^3 (1.9 \times 10^7 \text{Bq/m}^3) \text{ 137Cs equivalent}$; or
(b) the measuring device is out of order.

(1.9) The total activity release must not exceed a specified value in Ci/a (or Bq/a) to be determined as the sum of the releases of the specific radionuclides except tritium (see Table A2—III). The release of tritium must not exceed a specified value in Ci/a (or Bq/a). The quarterly releases must not exceed one half of the licensed yearly releases (see 2.1, 2.2).

The applicant in a licensing procedure has to prove that the requested limit of release is necessary, owing to the state of technology, taking different operating conditions into account. From experience, the liquid release rates of pressurized light-water reactors of 1000 MW electrical power can be assumed to be 900 Ci/a ($3.3 \times 10^{13} \text{Bq/a}$) of tritium ($^3\text{H}$) and 1 Ci/a ($3.7 \times 10^{10} \text{Bq/a}$) of other radioactive materials. Since the estimates should be conservative, it seems appropriate to assume the following yearly release rates for liquid effluents:

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Release Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tritium</td>
<td>$1000 - 2000 \text{Ci/1000 MW(e)}$</td>
</tr>
<tr>
<td></td>
<td>($(3.7 - 7.4) \times 10^{13} \text{Bq/1000 MW(e)}$)</td>
</tr>
<tr>
<td>Other radionuclides</td>
<td>$3 - 5 \text{Ci/1000 MW(e)}$</td>
</tr>
<tr>
<td></td>
<td>($(1.1 - 1.9) \times 10^{11} \text{Bq/1000 MW(e)}$)</td>
</tr>
</tbody>
</table>

When establishing activity release limits, it has to be ascertained that the limits of radiation exposure to man set up in the atomic licensing procedure or the Radiation Protection Ordinance are not exceeded.

(1.10) The released amounts of radioactive materials including tritium have to be recorded (see 2.2).

(1.11) In the cooling-water discharge canal/discharge structure a continuously operating, recording, gamma-sensitive measuring device, with a detection limit of $10^{-7} \text{Ci/m}^3 (3.7 \times 10^3 \text{Bq/m}^3)$ of $\text{137Cs}$ equivalent, has to be installed and continuously operated; this automatically activates optical and acoustical warning signals in the control room if a concentration of $10^{-5} \text{Ci/m}^3 (3.7 \times 10^5 \text{Bq/m}^3)$ of $\text{137Cs}$ equivalent is exceeded (see 2.3).

(1.12) From the cooling-water discharge canal/discharge structure a daily sample of a volume of at least 1 litre has to be taken continuously by an automatically operating equipment. The daily samples collected over a period of one month have to be stored for 30 more days. After this time, a sample has to be composited, one part of which has to be analysed or made to be analysed according to the method described in para. 2.2. One litre of the composite sample has to be stored for one year.

To evaluate the upstream radioactivity load of the receiving water, daily samples from the cooling-water inlet have to be collected, measured and stored in the same way.
(1.13) Any authorities supervising compliance with these discharge conditions have to be given access to the operational records. The stored samples have to be handed out to them on request.

(1.14) Species and amount of discharged radioactive materials as well as the amount of cooling water and of liquid effluents have to be reported quarterly to the competent authorities. The reports have to classify:

(a) Total load;
(b) Mean values (daily, monthly, quarterly);
(c) Maximum values.

2. RADIOACTIVITY MEASUREMENTS

(2.1) To decide on the discharge of liquid effluents from the discharge tank (see 1.5) the gamma count-rate of the 1-litre sample has to be determined by integral gamma measurement for energies above 0.1 MeV. The value of the activity concentration in Ci/m$^3$ (Bq/m$^3$) is calculated by comparing with $^{137}$Cs ($^{137}$Cs equivalent). The conversion of the determined gamma count-rate into Ci/m$^3$ (Bq/m$^3$) is done by comparing the ratio of activity/count-rate to that determined by measurement of a 1-litre $^{137}$Cs standard solution under the same conditions. The single statistical error of this measurement must not exceed ±10%.

(2.2) To determine the total discharge (see 1.4, 1.9, 1.10) the weekly composite samples have to be analysed or made to be analysed for their content of gamma-emitting radionuclides by gamma spectroscopy within one week after the last single sample was taken. The detection limits given in Table A2—III have to be attained.

Within one month after compositing, the monthly samples have to be analysed or made to be analysed for their content of $^{89}$Sr and $^{90}$Sr; the quarterly samples have to be analysed for their $^3$H content. Here, too, the detection limits of Table A2—III have to be attained.

The measured activities of the specific radionuclides have to be corrected for the mid-point of the sampling period, taking their radioactive half-life into account. The results have to be recorded according to para. 1.10.

(2.3) To monitor the water released from the nuclear power station to the receiving water, the gamma count-rate of an integral measurement for energies above 0.1 MeV has to be recorded by a continuously recording measuring device in the discharge canal/discharge structure. The time constant of the device has to be chosen in such a way as to reproduce an activity concentration of $10^{-3}$ Ci/m$^3$ ($3.7 \times 10^5$ Bq/m$^3$) $^{137}$Cs equivalent with a precision of 10%.
MONITORING OF RADIOACTIVE RELEASES
AT THE GARIGLIANO NUCLEAR POWER STATION OF THE
ENTE NAZIONALE PER L'ENERGIA ELETTRICA (ENEL), ITALY

L. Antonucci, Italy

1. DESCRIPTION OF THE STATION
NATURE AND AMOUNT OF RADIONUCLIDES RELEASED

1.1. Site

The Garigliano station is located in Southern Italy, between Rome and Naples, in the valley of the Garigliano river, approximately 7 km from the Tyrrhenian Sea.

1.2. General description of the station

The Garigliano nuclear power station is equipped with a boiling water reactor with a thermal output of 506 MW, corresponding to an electrical output of 160 MW.

The steam produced in the reactor goes directly into the turbine, and the condensate is first purified on ion-exchange resin beds and then returned to the process line.

Condenser cooling is performed in an open cycle with water from the Garigliano river, drawn and returned at a rate of 10 m³/s.

At present, the core is made up of 208 fuel assemblies, a number of which contain enriched uranium and the remaining mixed (U, Pu) oxides, and is partially refuelled every eighteen months.

1.3. Liquid effluents

The radioactive liquid effluents originate from:
(a) Floor drains;
(b) Solutions for regeneration of the resins used for condensate treatment, and solutions resulting from equipment decontamination and from the radiochemical laboratory;
(c) Solutions resulting from laundering of contaminated protective clothing.

The specific activity of the liquid effluents is between $10^{-2}$ and $10^{-5}$ Ci/m³ ($3.7 \times 10^8$ and $3.7 \times 10^5$ Bq/m³). The main radioisotopes present are: $^{60}$Co, $^{58}$Co, $^{54}$Mn, $^{110m}$Ag, $^{137}$Cs, $^{134}$Cs, $^{131}$I, $^{89}$Sr, $^{90}$Sr, $^{140}$Ba-La.

Table A2–IV lists the releases effected in the period 1965–1976.
### TABLE A2—IV. RADIOACTIVE LIQUID EFFLUENTS RELEASED IN THE PERIOD 1965—1976

<table>
<thead>
<tr>
<th>Year</th>
<th>Discharges (m³)</th>
<th>Activity released (excepting (^3)H)</th>
<th>(^3)H released</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Ci)</td>
<td>(Bq)</td>
</tr>
<tr>
<td>1965</td>
<td>8021</td>
<td>2.3</td>
<td>8</td>
</tr>
<tr>
<td>1966</td>
<td>6997</td>
<td>2.8</td>
<td>7</td>
</tr>
<tr>
<td>1967</td>
<td>7864</td>
<td>3.4</td>
<td>8</td>
</tr>
<tr>
<td>1968</td>
<td>8566</td>
<td>4.8</td>
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<tr>
<td>1969</td>
<td>6726</td>
<td>9.0</td>
<td>7</td>
</tr>
<tr>
<td>1970</td>
<td>5048</td>
<td>13.2</td>
<td>5</td>
</tr>
<tr>
<td>1971</td>
<td>4292</td>
<td>19.1</td>
<td>5</td>
</tr>
<tr>
<td>1972</td>
<td>4037</td>
<td>14.4</td>
<td>3</td>
</tr>
<tr>
<td>1973</td>
<td>5260</td>
<td>3.7</td>
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<tr>
<td>1974</td>
<td>2482</td>
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<td>1.3</td>
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<tr>
<td>1975</td>
<td>4629</td>
<td>3.1</td>
<td>5.3</td>
</tr>
<tr>
<td>1976</td>
<td>3592</td>
<td>3.7</td>
<td>17.9</td>
</tr>
</tbody>
</table>

### 1.4. Airborne effluents

The radioactive airborne effluents are constituted mainly of:

(a) Ventilation air from the reactor building, turbine building, radioactive waste treatment building and some of the offices (total discharge: approximately 100 000 m³/h);

(b) Incondensables, consisting of air, radiolytic gases, fission and activation gases leaving the main condenser, commonly called 'off-gas' (discharge: approximately 30 m³/h);

(c) Incondensables, consisting mainly of air containing traces of radiolytic gases, and fission and activation gases from the turbine seal steam condenser (discharge: approximately 600 m³/h).

The main noble gases discharged are: \(^{138}\)Xe, \(^{135}\)Xe, \(^{135m}\)Xe, \(^{133}\)Xe, \(^{88}\)Kr, \(^{87}\)Kr, \(^{85m}\)Kr. The long-lived radioactive particulates are mainly: \(^{140}\)Ba-La, \(^{89}\)Sr, \(^{137}\)Cs, \(^{134}\)Cs, \(^{90}\)Sr, \(^{60}\)Co. The only long-lived halogen released is \(^{131}\)I. Tritium is discharged mainly in the form of tritiated steam in the ventilation air.

Table A2—V lists the releases effected in the period 1965—1976.

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### TABLE A2–V. NOBLE GASES RELEASED AT THE STACK IN THE PERIOD 1965–1976

<table>
<thead>
<tr>
<th>Year</th>
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### 2. RADIOACTIVE EFFLUENT TREATMENT

#### 2.1. Liquid effluents

Liquid effluents are treated in three types of tanks, depending on the origin of the waste (see Fig. A2–1):

(a) Floor drain collection tank;
(b) Regenerative solution collection tank;
(c) Laundry solution collection tank.

Before being discharged, the effluents are filtered, evaporated or treated chemically, depending on the results of the analyses (measurement of specific radioactivity, physico-chemical properties of the radioisotopes present, conductivity). The wastes are discharged into the Garigliano river through the condenser coolant tailrace, after sampling and radiochemical analysis of the liquids in each tank.

#### 2.2. Airborne effluents

Airborne effluents are discharged on a continuous basis through a 91.5 m stack with an outlet diameter of 1.7 m. The actual altitude of release depends
FIG.A2-1. Garigliano station liquid effluent treatment system.
FIG.A2-2. Flow diagram of elimination of the incondensables.
on the weather conditions as well as on the gas flow velocity (about 12 m/s) and varies between 100 and 150 m (Fig. A2–2).

The incondensables extracted from the main condenser by ejectors are conveyed through a hold-up line (approx. 55 min delay) to two HEPA absolute filters of fibre glass in series (99.9% filtering efficiency for particles of 0.3 μm in dia.), diluted with the ventilation air and then discharged through the stack.

The incondensables from the turbine seal steam condenser are conveyed through a 3-min hold-up line to the stack. This source contributes to the total activity released by about 0.1–0.2% (measured value).

3. SAMPLING POINTS AND TECHNIQUES

3.1. Liquid effluents

The liquid waste in the sampling tanks is monitored in two ways:

(a) Intermittent monitoring of samples taken from each tank before discharge, and laboratory measurement;

(b) Continuous monitoring at the mixing point before discharge into the river.

3.1.1. Intermittent monitoring

As previously stated, the radioactive effluents are collected in the floor drain collection tank, the regenerant neutralization tank and the two laundry solution tanks. Every discharge is to be authorized in writing, by a designated person. Before discharging each tank, the specific radioactivity of its contents is measured on a 1000-ml sample by means of a gross-gamma detector calibrated for this purpose.

All the samples from each tank collected in one month are mixed in volumes proportional to the discharged volumes to form three integral monthly samples typical of the contents of the three types of tanks. These samples are subjected to several analyses in order to have a precise balance of the radioactivity discharged into the river each month.

3.1.2. Continuous monitoring

Continuous monitoring is, in its turn, performed in two ways:

(a) The radioactivity of the water from the condenser is measured continuously in the well where it is mixed with the radioactive effluents before discharge into the river. For this purpose, a detector enclosed in a sealed steel tube is immersed in the mixing well.
FIG. A2–3. Continuous monitoring system of the incondensables.
(b) Continuous sampling and intermittent monitoring of radioactivity in the water in the mixing well. For this purpose, use is made of a pump, timer and hold-up tank. A 5-litre sample is taken daily from the hold-up tank, which is then drained. The samples of a whole month are put together and analysed in the radiochemical laboratory.

3.2. Airborne effluents

Airborne effluents are monitored by one of the following methods, depending on the effluent.

3.2.1. Noble gases

(a) Continuous monitoring, with recording and alarm, of the incondensables extracted from the main condenser by means of two independent d.c. ionization chambers located upstream of the hold-up line (Fig. A2–3).

(b) Continuous monitoring of the effluents, with recording and alarm, on samples taken continuously at the stack, by means of a NaI(Tl) inorganic scintillator (Fig. A2–4). The samples are taken by means of a probe and a pump with the following characteristics:

- Isokinetic sampling probe with four sampling tubes, 1 cm in dia.; the intake flow-rate is about 9 m$^3$/h, the gas velocity in the stack at the probe level is about 6 m/s.
- Oil-less vacuum pump with an operating head at the intake of about 350 mmHg absolute.

(c) Intermittent monitoring by means of analyses of samples taken weekly from the main condenser, measurement of the flow-rate of the incondensables and of the time required by the gas to reach the stack from the ejectors. The gas sample is introduced into a serum bottle by means of a hypodermic needle fitted with a pin valve. The stack release rate in $\mu$Ci/s (Bq/s) thus determined is also used to calibrate the continuous monitoring systems described in (a) and (b) above.

3.2.2. Halogens and particulates

The system used to monitor noble gases released at the stack is also used for continuous sampling of radioactive particulates and iodine isotopes (sampling rate 8 m$^3$/h) on SS-5892 paper filters and CESCO active-carbon cartridges.

3.2.3. Tritium

This isotope is monitored on samples of air released at the stack.
FIG. A2–4. Stack monitoring.
4. MEASUREMENT TECHNIQUES

4.1. Liquid effluents

4.1.1. Intermittent monitoring as in §3.1.1

4.1.1.1. Gross-gamma scanning

The gross-gamma scanning equipment is calibrated by means of the integral monthly samples taken in the preceding month, on the basis of the total concentration resulting from the activity of the gamma emitters as measured by Ge(Li) detectors plus the activity of $^{89}$Sr and $^{90}$Sr determined by radiochemical separation.

4.1.1.2. Radiochemical analyses

(a) Determination of the gamma emitters by means of Ge(Li) detectors for every batch of liquid waste.
(b) Determination of $^{89}$Sr and $^{90}$Sr (by radiochemical separation), total beta and tritium in the floor drains and neutralizer solutions.
(c) Alpha activity discharged in the preceding month, calculated by multiplying the alpha activity measured in the primary circuit water by the total volume discharged.

The sensitivity of the system is of the order of $10^{-9}$ Ci/m$^3$ (37 Bq/m$^3$), corresponding to a few microcuries per month, or a maximum dose of about $10^{-6}$ mrem/month to the most exposed group.

4.1.2. Continuous monitoring as in §3.1.2

4.1.2.1. Continuous monitoring

The system consists of:

(a) Gamma detector: A NaI(Tl) scintillator of the 2 in \( \times \) 2 in (5 cm \( \times \) 5 cm) integral-line type. Resolving power: 8% on $^{137}$Cs. The detector, photomultiplier and cathode follower are housed in a cylindrical steel tube.
(b) Amplifier: Solid-state linear unit with a scale changer (range 0–10$^7$ counts/min).
(c) Multi-pen potentiometric recorder.
The system sensitivity is about $2 \times 10^{-6} \, \mu\text{Ci/ml} \, (7.4 \times 10^{-2} \, \text{Bq/ml})$ of $^{60}\text{Co}$, corresponding to an increase of 1000 counts/min over a background of 3000 counts/min. The sensitivity was determined experimentally both by immersing the detector in a $^{60}\text{Co}$ solution of known activity concentration and by discharging a tank containing a known $^{60}\text{Co}$ activity concentration at a given discharge rate.

4.1.2.2. Intermittent monitoring

The sample is subjected to a series of radiochemical separations to determine the average concentrations of caesium ($^{137}\text{Cs}$ and $^{134}\text{Cs}$), activation products and metal corrosion products ($^{60}\text{Co}$) in the waste waters. The precision achievable is of the order of $5 \times 10^{-10} \, \mu\text{Ci/m}^3 \, (18.5 \, \text{Bq/m}^3)$ so that it is possible to detect a monthly minimum of some $10^{-2} \, \mu\text{Ci} \, (3.7 \times 10^8 \, \text{Bq})$. However, to increase the response time of the system, which provides only a monthly value, a gross measurement is taken every day on 100 cm$^3$ of water. The sensitivity of the monitoring system is of the order of $5 \times 10^{-8} \, \mu\text{Ci/m}^3 \, (1.9 \times 10^3 \, \text{Bq/m}^3)$.

4.2. Airborne effluents

4.2.1. Monitoring of noble gases as in §3.2.1

4.2.1.1. Continuous monitoring of the incondensables at the ejector outlet with ionization chambers

The system consists of:

(a) Two ionization chambers filled with nitrogen at atmospheric pressure.

(b) A logarithmic amplifier with a one-decade scale that can be changed for six different readings from 1 mR/h to $10^6$ mR/h. The amplifier is equipped with an alarm circuit and a tripping circuit. The alarm is set at a value corresponding to a stack release of 100 000 $\mu$Ci/s ($3.7 \times 10^9$ Bq/s). Tripping occurs when the stack release rate is 10 Ci/s ($3.7 \times 10^{11}$ Bq/s). A timer allows the trip to be cleared by the operator within 15 min. The tripping circuit causes closure of the valve at the end of the hold-up line.

(c) A two-pen potentiometric recorder, with a sensitivity of 1.5 mR/h (background: approx. 5 mR/h), expressed as the release rate of the seven noble gases ($^{133}\text{Xe}$, $^{135}\text{Xe}$, $^{135m}\text{Xe}$, $^{138}\text{Xe}$, $^{85}\text{mKr}$, $^{87}\text{Kr}$, $^{88}\text{Kr}$) at the stack, which is of the order of 15 $\mu$Ci/s ($5.6 \times 10^5$ Bq/s).

4.2.1.2. Continuous sampling and monitoring of the airborne effluents at the stack by means of:
(a) A gamma detector: a 1.5 in × 1 in (3.8 cm × 2.5 cm) NaI(Tl) scintillator with a resolving power of 12% on the $^{137}$Cs peak. The detector is immersed in a shielded vessel through which the gas flows.

(b) A solid-state rate meter/analyser, consisting of an amplifier, an analyser and an alarm system (low and high). The logarithmic scale ranges from 10 to $10^6$ counts/min.

(c) A two-pen potentiometric recorder.

The system is equipped with two calibration sources of $^{133}$Ba and $^{137}$Cs plus an internal $^{137}$Cs source for a check of the instrument operation. The total discharge rate at the stack is of the order of 100,000 m$^3$/h, measured by a Pitot tube located on the station ventilation duct. The monitoring intake rate is 150 l/min. The volume of the gas monitoring chamber is 3130 ml and the lead thickness is 10 cm. The system sensitivity is of the order of 50 µCi (1.9 × $10^6$ Bq), corresponding to about twice the background (150 counts/min). Expressed in specific activity, the sensitivity is of the order of $2.7 \times 10^{-6}$ µCi/ml (10$^5$ Bq/ml).

4.2.1.3. Intermittent monitoring of the release rate of noble gases by means of:

(a) Gamma spectrometry (Ge(Li)) of the serum bottle.

(b) Calculation of the isotopic composition of the noble gas mixture referred to in §4.2.1.1.

(c) Analysis of the composition of the incondensables mixture from the main condenser (air, hydrogen, oxygen).

(d) Measurement of the mixture flow-rate by means of a calibrated orifice in the pipe leaving the end condenser (Fig. A2–2).

Provision has been made in the monitoring system for automatic correction of the pressure, temperature and density. The system consists of the following components:

(a) Calibrated orifice (quarter of a circle diaphragm) with a diameter of 25.625 mm (pipe diameter 70 mm). Throttling ratio: 0.134. The maximum pressure drop is 64 mmH$_2$O, corresponding to 70 m$^3$/h of a gas mixture consisting of H$_2$ (50%), O$_2$ (30%) and N$_2$ (20%).

(b) Flow-rate transducer.

(c) Pressure transducer.

(d) Temperature transducer with a Pt-resistance thermometer.

(e) Density adjuster calibrated for the H$_2$/N$_2$ ratio.

(f) Analogue computer for flow-rate correction as a function of the variation in density, pressure and temperature.

(g) Recorder.
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<td>1.1</td>
<td>0.3</td>
<td>8.4</td>
</tr>
<tr>
<td>La-140 (10^10 Bq)</td>
<td>3.3</td>
<td>1.1</td>
<td>2.2</td>
<td>0.37</td>
<td>0.33</td>
<td>0.15</td>
<td>0.4</td>
<td>1.1</td>
</tr>
<tr>
<td>(%)</td>
<td>9.9</td>
<td>2.3</td>
<td>3.1</td>
<td>0.7</td>
<td>2.5</td>
<td>1.1</td>
<td>0.3</td>
<td>8.4</td>
</tr>
<tr>
<td>Cs-134 (10^10 Bq)</td>
<td>0.30</td>
<td>1.1</td>
<td>8.5</td>
<td>9.3</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>(%)</td>
<td>0.9</td>
<td>2.3</td>
<td>12.1</td>
<td>17.5</td>
<td>10.9</td>
<td>10.5</td>
<td>13.0</td>
<td>11.2</td>
</tr>
<tr>
<td>I-131 (10^10 Bq)</td>
<td>0.30</td>
<td>1.1</td>
<td>12.2</td>
<td>1.9</td>
<td>1.5</td>
<td>0.37</td>
<td>0.26</td>
<td>0.74</td>
</tr>
<tr>
<td>(%)</td>
<td>0.9</td>
<td>2.3</td>
<td>17.3</td>
<td>3.5</td>
<td>10.9</td>
<td>2.6</td>
<td>2.3</td>
<td>5.6</td>
</tr>
<tr>
<td>Mn-54 (10^10 Bq)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.15</td>
<td>0.26</td>
<td>0.15</td>
</tr>
<tr>
<td>(%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.0</td>
<td>2.3</td>
<td>1.1</td>
</tr>
<tr>
<td>Ag-110m (10^10 Bq)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.07</td>
<td>0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>(%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5</td>
<td>1.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Fe-59 (10^10 Bq)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.0026</td>
<td>0.007</td>
<td>0.02</td>
</tr>
<tr>
<td>(%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.02</td>
<td>0.06</td>
<td>0.2</td>
</tr>
<tr>
<td>Total (10^10 Bq)</td>
<td>33.7</td>
<td>48.1</td>
<td>70.7</td>
<td>52.9</td>
<td>14.3</td>
<td>14.1</td>
<td>11.5</td>
<td>13.3</td>
</tr>
<tr>
<td>(%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
TABLE A2-VII. AVERAGE YEARLY PERCENTAGE ISOPTIC COMPOSITION OF NOBLE GAS RELEASED AT THE STACK IN 1974—1976

<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>1974 (%)</th>
<th>1975 (%)</th>
<th>1976 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Xe-138</td>
<td>9.5</td>
<td>15.1</td>
<td>18.7</td>
</tr>
<tr>
<td>Xe-135m</td>
<td>5.2</td>
<td>7.5</td>
<td>6</td>
</tr>
<tr>
<td>Xe-135</td>
<td>31.1</td>
<td>27.7</td>
<td>27.5</td>
</tr>
<tr>
<td>Xe-133</td>
<td>22.6</td>
<td>17.8</td>
<td>17</td>
</tr>
<tr>
<td>Kr-88</td>
<td>10.9</td>
<td>10.8</td>
<td>11.7</td>
</tr>
<tr>
<td>Kr-87</td>
<td>13.9</td>
<td>14.4</td>
<td>12.2</td>
</tr>
<tr>
<td>Kr-85m</td>
<td>6.8</td>
<td>6.7</td>
<td>6.9</td>
</tr>
</tbody>
</table>

The correct calibration of the flow-rate monitoring system is checked by calculating the transit time of two radioisotopes (135Xe and 135mXe) from the ejectors to the stack on the basis of their decay and of the volume of the hold-up pipe.

4.2.2. Halogen and particulate monitoring as in §3.2.2

The following measurements are performed:

(a) Gamma spectrometry (Ge(Li)) of the radioactive carbon every fortnight.

(b) Gamma spectrometry (Ge(Li)) and radiochemical separation of the strontium isotopes on the monthly batch of filters that were changed daily.

The long-lived halogen and particulate release rate is determined on the basis of the results of the foregoing analyses once the volume of the sampled air and the discharge rate are known. The discharge rate is continuously measured by means of a Pitot tube installed in the station ventilation duct before it enters the stack.

The particulates of interest are those that have a half-life of more than eight days; the sensitivity of the system for these particulates is about $1 \times 10^{-7} \mu\text{Ci/s}$ ($3.7 \times 10^{-3} \text{Bq/s}$) (with reference to $^{137}\text{Cs}$). The sensitivity in respect of $^{131}\text{I}$ is of the order of $1 \times 10^{-6} \mu\text{Ci/s}$ ($3.7 \times 10^{-2} \text{Bq/s}$).
<table>
<thead>
<tr>
<th>Radioisotope</th>
<th>1974</th>
<th>1975</th>
<th>1976</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-3</td>
<td>(Ci) NM</td>
<td>~1</td>
<td>14.7</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>~3.7 X 10^{10}</td>
<td>54.4 X 10^{10}</td>
</tr>
<tr>
<td>I-131</td>
<td>(Ci) 2.4 X 10^{-2}</td>
<td>1.6 X 10^{-2}</td>
<td>3.5 X 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>(Bq) 8.9 X 10^{6}</td>
<td>5.9 X 10^{8}</td>
<td>13.0 X 10^{6}</td>
</tr>
<tr>
<td>Sr-90</td>
<td>(Ci) NM</td>
<td>5.7 X 10^{-4}</td>
<td>6.7 X 10^{-5}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>21.1 X 10^{6}</td>
<td>24.8 X 10^{6}</td>
</tr>
<tr>
<td>Sr-89</td>
<td>(Ci) NM</td>
<td>2.2 X 10^{-1}</td>
<td>6 X 10^{-3}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>8.1 X 10^{9}</td>
<td>22.2 X 10^{7}</td>
</tr>
<tr>
<td>Cs-137</td>
<td>(Ci) NM</td>
<td>8 X 10^{-3}</td>
<td>9.1 X 10^{-3}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>29.6 X 10^{7}</td>
<td>33.7 X 10^{7}</td>
</tr>
<tr>
<td>Cs-134</td>
<td>(Ci) NM</td>
<td>7.6 X 10^{-5}</td>
<td>5.2 X 10^{-3}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>28.1 X 10^{5}</td>
<td>19.2 X 10^{7}</td>
</tr>
<tr>
<td>Ba-140/La-140</td>
<td>(Ci) NM</td>
<td>1.4 X 10^{-1}</td>
<td>1.1 X 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>5.2 X 10^{9}</td>
<td>4.0 X 10^{8}</td>
</tr>
<tr>
<td>Co-60</td>
<td>(Ci) NM</td>
<td>3.1 X 10^{-4}</td>
<td>1.7 X 10^{-4}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>11.5 X 10^{6}</td>
<td>6.3 X 10^{6}</td>
</tr>
<tr>
<td>Co-58</td>
<td>(Ci) NM</td>
<td>9.6 X 10^{-5}</td>
<td>4.5 X 10^{-6}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>35.5 X 10^{5}</td>
<td>16.7 X 10^{4}</td>
</tr>
<tr>
<td>Mn-54</td>
<td>(Ci) NM</td>
<td>7.6 X 10^{-6}</td>
<td>5.2 X 10^{-6}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>28.1 X 10^{4}</td>
<td>19.2 X 10^{4}</td>
</tr>
<tr>
<td>Ag-110m</td>
<td>(Ci) NM</td>
<td>NM</td>
<td>6.2 X 10^{-5}</td>
</tr>
<tr>
<td></td>
<td>(Bq) NM</td>
<td>NM</td>
<td>22.9 X 10^{5}</td>
</tr>
</tbody>
</table>

NM = not measured.
4.2.3. Monitoring of tritium as in §3.2.2

The release rate of tritium is determined quarterly by measuring:

(a) The absolute humidity in g/m$^3$ of the air released at the stack;
(b) Tritium concentration (with a liquid scintillator) in the condensate of the air sample;
(c) Total ventilation air flow-rate.

The sensitivity of the monitoring system is of the order of $5 \times 10^{-3}$ $\mu$Ci/s ($1.9 \times 10^2$ Bq/s).

5. MONITORING RESULTS

5.1. Liquid effluents

Table A2—VI gives the activities discharged per year in the period 1969—1976, broken down by radioisotopes (except for tritium) and the percentage composition. On the basis of the data in Tables A2—IV and A2—VI, the following comments can be made:

(a) The activity discharged per year (excepting tritium) has increased steadily in the period 1965—1971, reaching a peak of nearly 20 Ci ($7.4 \times 10^{11}$ Bq). At the same time the isotopic composition has changed as a result of the gradual increase of fission products in the primary circuit water. This was due partly to the increasing number of faulty fuel elements and partly to the gradual increase of leakage from the secondary steam generator tube bundle.
(b) The reduced activity release starting from 1972 is to be attributed to repairs of the steam generator tube bundles, to better management of the waste collection system and to intensive use of the evaporator.

5.2. Airborne effluents

The annual average of noble gas activity fluctuates around 5 mCi/s (1.9 \times 10^8 \text{ Bq/s}) with a few peaks in 1971 and 1976 due to the increased number of faulty fuel assemblies at the end of the cycle. The $^{131}$I activity released was always very low, i.e. a few tens of mCi/a (3.7 \times 10^7 \text{ Bq/a} \equiv 1 \text{ mCi/a}).

The particulates are essentially composed of fission products ($^{140}$Ba and $^{89}$Sr) and the related activity released was less than 1 Ci/a ($3.7 \times 10^{10} \text{ Bq/a}$).

MONITORING OF GASEOUS AND LIQUID EFFLUENTS AT FRENCH NUCLEAR POWER PLANTS

L. Fitoussi, France

Uniform sampling and measuring methods are used in monitoring waste at the nuclear power plants operated by Electricité de France. In the following, a brief description of the different power plants is given; diagrams of ventilation and liquid effluent discharge circuits are attached. Some general information is given about the releases from the power plants and also the composition of the liquid effluents. Lastly, the sampling methods and measurement techniques are described.

DESCRIPTION OF THE POWER PLANTS

(a) Graphite/gas power plants with a non-integrated primary circuit (heat-exchangers outside the reactor vessel) such as Chinon-2 (210 MW(e)) and Chinon-3 (400 MW(e)); Chinon-1 was shut down in 1973. The liquid effluents from these plants are monitored by the Service de contrôle des matériaux irradiés (formerly the Atelier des matériaux irradiés); the fuel elements are kept in containers during their stay in the cooling pond.

(b) Graphite/gas power plants with an integrated primary circuit (heat exchanger and reactor in the same prestressed concrete vessel) such as St. Laurent-1 (460 MW(e)), St. Laurent-2 (515 MW(e)) and Bugey-1 (540 MW(e)). The fuel elements from these plants are not kept in containers during their stay in the cooling pond.

(c) Pressurized-water plant, Chooz (305 MW(e)), the fuel of which is clad in stainless steel. Other power-plants belonging to this group are the 900 MW(e) PWRs at Fessenheim (two units) and Bugey (four units), the fuel of which is clad in Zircaloy.

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## TABLE A2-IX. GASEOUS RELEASES FROM NUCLEAR POWER PLANTS

<table>
<thead>
<tr>
<th>Year</th>
<th>Chinon</th>
<th>St. Laurent</th>
<th>Bugey</th>
<th>Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GR (kCi)</td>
<td>APV (mCi)</td>
<td>GR (kCi)</td>
<td>APV (mCi)</td>
</tr>
<tr>
<td>1971</td>
<td>4.2</td>
<td>18</td>
<td>3.4</td>
<td>47</td>
</tr>
<tr>
<td>1972</td>
<td>12</td>
<td>180</td>
<td>3.9</td>
<td>140</td>
</tr>
<tr>
<td>1973</td>
<td>2.8</td>
<td>42</td>
<td>5.0</td>
<td>37</td>
</tr>
<tr>
<td>1974</td>
<td>2.1</td>
<td>18</td>
<td>4.3</td>
<td>20</td>
</tr>
<tr>
<td>1975</td>
<td>6.0</td>
<td>31</td>
<td>3.5</td>
<td>17</td>
</tr>
<tr>
<td>1976</td>
<td>4.9</td>
<td>20</td>
<td>2.9</td>
<td>13</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Year</th>
<th>Chinon</th>
<th>St. Laurent</th>
<th>Bugey</th>
<th>Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GR (Bq)</td>
<td>APV (Bq)</td>
<td>GR (Bq)</td>
<td>APV (Bq)</td>
</tr>
<tr>
<td>1971</td>
<td>15.2 $\times 10^{13}$</td>
<td>66.6 $\times 10^{7}$</td>
<td>12.6 $\times 10^{13}$</td>
<td>174 $\times 10^{7}$</td>
</tr>
<tr>
<td>1972</td>
<td>44.4 $\times 10^{13}$</td>
<td>2257 $\times 10^{7}$</td>
<td>14.4 $\times 10^{13}$</td>
<td>518 $\times 10^{7}$</td>
</tr>
<tr>
<td>1973</td>
<td>10.4 $\times 10^{13}$</td>
<td>155.4 $\times 10^{7}$</td>
<td>18.5 $\times 10^{13}$</td>
<td>137 $\times 10^{7}$</td>
</tr>
<tr>
<td>1974</td>
<td>7.8 $\times 10^{13}$</td>
<td>66.6 $\times 10^{7}$</td>
<td>15.9 $\times 10^{13}$</td>
<td>74 $\times 10^{7}$</td>
</tr>
<tr>
<td>1975</td>
<td>22.2 $\times 10^{13}$</td>
<td>114.7 $\times 10^{7}$</td>
<td>13.0 $\times 10^{13}$</td>
<td>62.9 $\times 10^{7}$</td>
</tr>
<tr>
<td>1976</td>
<td>18.1 $\times 10^{13}$</td>
<td>74.0 $\times 10^{7}$</td>
<td>10.7 $\times 10^{13}$</td>
<td>48.1 $\times 10^{7}$</td>
</tr>
</tbody>
</table>

GR — noble gases; APV — aerosols and volatile products; NM — not measured.
### TABLE A2–X. LIQUID RELEASES FROM NUCLEAR POWER PLANTS

<table>
<thead>
<tr>
<th>Year (Unit)</th>
<th>Chinon</th>
<th>St. Laurent</th>
<th>Bugey</th>
<th>Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total beta</td>
<td>$^3$H</td>
<td>Total beta</td>
<td>$^3$H</td>
</tr>
<tr>
<td>1971 (Ci)</td>
<td>2 NM</td>
<td>2.2 NM</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(10$^{10}$ Bq)</td>
<td>7.4 NM</td>
<td>8.1 NM</td>
<td>0.1 NM</td>
<td>44.4 6 660</td>
</tr>
<tr>
<td>1972 (Ci)</td>
<td>3 NM</td>
<td>9.4 NM</td>
<td>0.37 NM</td>
<td>12 1 800</td>
</tr>
<tr>
<td>(10$^{10}$ Bq)</td>
<td>11.1 NM</td>
<td>34.8 NM</td>
<td>8.2 1 900</td>
<td></td>
</tr>
<tr>
<td>1973 (Ci)</td>
<td>3.3 NM</td>
<td>7.3 NM</td>
<td>1.6 NM</td>
<td>30.3 7 030</td>
</tr>
<tr>
<td>(10$^{10}$ Bq)</td>
<td>12.2 NM</td>
<td>27.1 NM</td>
<td>5.9 NM</td>
<td>31.8 9 250</td>
</tr>
<tr>
<td>1974 (Ci)</td>
<td>0.4 NM</td>
<td>4.2 400</td>
<td>60 820</td>
<td>8.6 3 300</td>
</tr>
<tr>
<td>(10$^{10}$ Bq)</td>
<td>1.5 NM</td>
<td>15.5 1480</td>
<td>222 3034</td>
<td>31.8 12 210</td>
</tr>
<tr>
<td>1975 (Ci)</td>
<td>0.7 150</td>
<td>4.7 700</td>
<td>14 240</td>
<td>8.6 2 500</td>
</tr>
<tr>
<td>(10$^{10}$ Bq)</td>
<td>2.6 555</td>
<td>17.4 2590</td>
<td>51.8 888</td>
<td>31.8 9 250</td>
</tr>
<tr>
<td>1976 (Ci)</td>
<td>0.6 100</td>
<td>3.0 500</td>
<td>3.6 200</td>
<td>2.6 1 900</td>
</tr>
<tr>
<td>(10$^{10}$ Bq)</td>
<td>2.2 370</td>
<td>11.1 1850</td>
<td>13.3 740</td>
<td>9.6 7 030</td>
</tr>
</tbody>
</table>

NM – not measured.

### NATURE AND QUANTITY OF THE EFFLUENTS

Tables A2–IX and A2–X show the activities released in the form of noble gases, aerosols and volatile products (except tritium) in gaseous effluents and in the form of tritium in liquid effluents. The results of vented air sampling (by bubbling through a liquid) indicate that the activities released do not exceed a few tens of curies (tera becquerels) per year.

The main radionuclides released in gaseous effluents are:

(a) Rare gases: Argon-41 in the graphite/gas reactors, xenon-133 and xenon-135 in the Chooz reactor;

(b) Aerosols: Cobalt-60, which accounts for most of the Chinon releases;

(c) Volatile products: Iodine-131, which predominates at the other power plants.

A detailed balance was drawn up in 1976 for liquid effluents (Table A2–XI).
TABLE A2-XI. ACTIVITY OF THE RADIONUCLIDES IDENTIFIED IN LIQUID EFFLUENTS

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Radioactivity released</th>
<th>Chinon</th>
<th>St. Laurent</th>
<th>Bugey</th>
<th>Chooz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Ci/a)</td>
<td>(10^10 Bq/a)</td>
<td>(Ci/a)</td>
<td>(10^10 Bq/a)</td>
</tr>
<tr>
<td>H-3</td>
<td></td>
<td>110</td>
<td>407</td>
<td>510</td>
<td>1887</td>
</tr>
<tr>
<td>S-35(^a)</td>
<td></td>
<td>0.15</td>
<td>0.56</td>
<td>6.4</td>
<td>23.7</td>
</tr>
<tr>
<td>Cr-51</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.008</td>
<td>0.030</td>
</tr>
<tr>
<td>Mn-54</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.007</td>
<td>0.026</td>
</tr>
<tr>
<td>Co-58</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Co-60</td>
<td></td>
<td>0.05</td>
<td>0.19</td>
<td>0.13</td>
<td>0.48</td>
</tr>
<tr>
<td>Zn-65</td>
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<td>-</td>
<td>-</td>
<td>0.015</td>
<td>0.056</td>
</tr>
<tr>
<td>Sr-90</td>
<td></td>
<td>0.030</td>
<td>0.110</td>
<td>0.053</td>
<td>0.196</td>
</tr>
<tr>
<td>Nb-95</td>
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<td>-</td>
<td>-</td>
<td>0.16</td>
<td>0.002</td>
</tr>
<tr>
<td>Zr-95</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.09</td>
<td>0.333</td>
</tr>
<tr>
<td>Sb-124</td>
<td></td>
<td>-</td>
<td>-</td>
<td>0.057</td>
<td>0.211</td>
</tr>
<tr>
<td>I-131</td>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cs-134</td>
<td></td>
<td>0.014</td>
<td>0.052</td>
<td>0.29</td>
<td>1.07</td>
</tr>
</tbody>
</table>

\(^a\) Estimated values.
TABLE A2—XI. (cont.)

<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Radioactivity released</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Chinon</td>
</tr>
<tr>
<td>Cs-137 (Ci/a)</td>
<td>0.14</td>
</tr>
<tr>
<td>(10^10 Bq/a)</td>
<td>0.52</td>
</tr>
<tr>
<td>La-140 (Ci/a)</td>
<td>-</td>
</tr>
<tr>
<td>(10^10 Bq/a)</td>
<td>-</td>
</tr>
<tr>
<td>Ce-144 (Ci/a)</td>
<td>-</td>
</tr>
<tr>
<td>(10^10 Bq/a)</td>
<td>-</td>
</tr>
</tbody>
</table>

MONITORING AND RELEASE METHODS

The methods employed differ somewhat, gaseous effluents being released continuously with the vented air, liquid effluents passing through a monitoring reservoir before release.

Gaseous effluents

The gaseous effluents consist essentially of vented air which has been contaminated as a result of leaks in the radioactive circuits. Emptying of the radioactive gas reservoirs in PWRs or of the primary circuit in graphite/gas reactors contributes only slightly to the gaseous effluents, owing to the activity reduction resulting from radioactive decay.

All the gaseous effluents pass through chimney stacks (the number of which is kept as low as possible) where a relatively constant flow-rate is maintained as far as possible. However, in some chimney stacks intended for the release of carbon dioxide the flow is intermittent. Each chimney stack is fitted with isokinetic intakes arranged across a diameter of the chimney stack (see Fig. A2—5). The sampled air passes simultaneously through a compensated chamber, which continuously measures the total beta activity of the filtered gases (reference standard: ^85Kr), and through a set of two filters — a paper filter which retains the aerosols and a carbon trap which fixes the volatile products. The carbon is a coal carbon impregnated with potassium iodide, 3 cm thick and traversed by the air at a rate of less than 0.5 m/s; its efficiency is greater than 90% for the penetrating forms of iodine when in continuous use for one week. A GM counter
above the filters indicates the radioactivity deposited in them and gives alarm if the level rises substantially above the equilibrium level obtained with the solid daughter nuclides of the short-lived noble gases which are trapped by the filter. It should be noted that the carbon trap also retains the noble gases temporarily. The filter and the trap are exchanged each week and measured in the laboratory.

**Liquid effluents**

All liquid effluents which are radioactive or capable of causing contamination are collected after treatment in monitoring reservoirs. When a reservoir is full, the contents are homogenized by stirring; a sample is then taken and measured in the laboratory.

When the result of the measurement is known, the reservoir can be emptied at such a rate that, given the flow-rate of the watercourse at the moment of discharge, the specific activity in the watercourse after dilution (assumed to be perfect) of the effluents does not exceed the value specified in the discharge authorization.

**MEASUREMENT TECHNIQUES**

The samples are analysed in the laboratory at the power plant as follows:

- **(a) Aerosol filter**: total beta (standard: \(^{90}\text{Sr} + \text{Y}\)) and possibly gamma spectrometry;
- **(b) Carbon trap**: gamma spectrometry;
- **(c) Water from the reservoirs**: total beta and tritium, and possibly total alpha and gamma spectrometry with specific measurement of \(^{90}\text{Sr}\).
The measurement thresholds are at least equal to the thresholds set by national legislation:

- Total beta measurement of the aerosols: $1 \times 10^{-11} \text{ Ci/m}^3 (3.7 \times 10^{-1} \text{ Bq/m}^3)$
- Total beta measurement of the liquids: $1 \times 10^{-7} \text{ Ci/m}^3 (3.7 \times 10^3 \text{ Bq/m}^3)$
- Total alpha measurement of the liquids: $1 \times 10^{-8} \text{ Ci/m}^3 (3.7 \times 10^2 \text{ Bq/m}^3)$
- Tritium measurement of the liquids: $1 \times 10^{-5} \text{ Ci/m}^3 (3.7 \times 10^5 \text{ Bq/m}^3)$

The total beta measurements are carried out, if necessary, by means of a low-background counter with a large surface and a thin window (0.9 mg/cm$^2$), which is also used for measuring the total alpha activity (proportional counter). Gamma spectrometry is always carried out with a Ge(Li) probe and replaces the total gamma measurement when the latter is not specified.

The tritium measurement is carried out by liquid scintillation after distillation of the sample.

The different measurement methods are described in Appendixes 1—7. Every three months a sample of each type (filter, trap, water) is sent to the Radiation Protection Department of Electricité de France for control analyses; the quality of the measurements is checked at the power plant. In addition, each month a sample is sent to the Central Service for Protection against Ionizing Radiation of the Ministry of Health, which makes a check independent of the one made by the nuclear plant operator.

Appendix 8 gives a diagram of the ventilation circuit of the Fessenheim nuclear power plant (Fig. A2-6) and a diagram of the liquid effluent treatment systems at the Chooz nuclear power plant (Fig. A2-7).

The releases from the power plants are entered in monthly statements of the type shown in Appendix 9.
Appendix 1

CONTINUOUS MEASUREMENT OF TOTAL BETA ACTIVITY OF FILTERED RADIOACTIVE GASES

This measurement is carried out by circulating the filtered gas either in a vessel placed opposite a scintillation beta detector or in an ionization chamber mounted differentially with respect to an identical airtight ionization chamber.

The response of the electronic measuring system is calibrated by reference to contamination of the carrier gas by $^{85}$Kr, which derives from a standard source in gaseous form and the specific activity of which is controlled, after dilution to the measurement range of the apparatus, by a reference ionization chamber (a Farraggi chamber).

Filtration ensures the protection of the measurement chamber against aerosol contamination$^2$, but it cannot prevent contamination by volatile products. This can be checked monthly by sweeping with contamination-free air, but generally the specific surface contamination by volatile products is sufficiently low, compared with that of the gas, so as not to give rise to a significant measurement. When contamination is detected, it can be eliminated by sweeping with non-radioactive hot air.

---

$^2$ The filter is placed just above the measurement chamber so as to reduce the formation of solid daughter nuclides of the fission gas.
Appendix 2

MEASUREMENT OF TOTAL BETA ACTIVITY OF THE AEROSOLS RETAINED BY A PAPER FILTER

Sample

Yellow filter paper with a useful diameter of 48 mm which has collected the aerosols contained in an air volume of the order of 450 m$^3$ for one week.

Delay

Five days between sampling of the filter and counting.

Equipment

A GM counter with a window thickness of at most 2 mg/cm$^2$ and a window surface area at least equal to the surface area of the filter to be measured. If the window surface area is less than the surface area of the filter, one must make sure periodically — by moving any significantly contaminated filter under the window — that the contamination is homogeneous.

A source consisting of $^{90}$Sr + $^{90}$Y deposited on a stainless-steel cup 54 mm in diameter and less than 10 mg/cm$^2$ thick.

A stainless-steel cup 54 mm in diameter for measuring the filter.

Measurement method

Determine the response of the detector for a given source position using the reference source of known activity $A_0$ giving rise to a net count $N_0$ (background subtracted) over a time $t_0$; do this once a month so as to ensure that the detector response is constant.

Leave the sample to be measured in the same counting position for a time $t$ giving a net count $N$.

Determine the activity $A$ of the sample:

$$A = A_0 \frac{N}{N_0} \frac{t_0}{t}$$

Measurement threshold

The sample material (especially the substance protecting it) and the measurement time must permit a significant measurement with a reference source activity of $10^{-10}$ Ci (3.7 Bq).

Note: Fixation of the contamination by pulverization of an adhesive aerosol is neither advised nor necessary in this case.
Appendix 3

MEASUREMENT OF TOTAL GAMMA ACTIVITY
OF THE VOLATILE PRODUCTS RETAINED BY A CARBON FILTER

Sample

A filter of activated charcoal, impregnated with potassium iodide, of diameter 48 mm and thickness 30 mm, on which are collected the volatile products contained in a volume of air of the order of 450 m³ over a period of one week.

Equipment

A gamma spectrometer, or a DCS assembly with a NaI(Tl) scintillator measuring 1 3/4 in × 2 in (~4.4 cm × 5 cm), or a similar instrument with the same detection threshold.

A reference source consisting of a carbon filter impregnated with 133Ba.

Measurement method

Place the carbon filters in their plastic or nylon envelopes with their plane faces towards the scintillator.

In the case of a total gamma measurement with a DCS 30 or a similar instrument, determine the response of the detector for a given source position using the reference source of known activity A₀ giving rise to a net count N₀ over a time t₀ (do this once a month so as to ensure that the detector response is constant); leave the sample to be measured in place for a time t giving a net count N; determine the activity A of the sample:

\[
A = A_0 \frac{N/t}{N_0/t_0}
\]

When a gamma spectrometer is used, add the activity identified in the form of 131I and a tenth of the activity identified in the form of 203Hg so as to obtain the activity A, representing the harm through ingestion.

Measurement threshold

The sample material and the measurement time must permit a significant measurement with a reference source activity of 10⁻¹⁰ Ci (3.7 Bq).

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³ This evaluation may be revised in the light of experience.
Appendix 4

MEASUREMENT OF TOTAL GAMMA ACTIVITY OF LIQUID EFFLUENTS

Sample

A flask with 50 cm$^3$ of liquid, taken from a drum after stirring to ensure homogeneity or from a pipe system where the liquid is circulating.

Equipment

A DCS 30 assembly with a NaI(Tl) scintillator measuring 1$\frac{3}{4}$ in X 2 in (~4.4 cm X 5 cm) or a similar instrument permitting attainment of the same detection threshold.

A reference source consisting of a flask with 50 cm$^3$ of a solution whose composition is representative of the discharged effluent ($^{137}$Cs, which ensures a long source life, is generally used as contaminant). One can also use an effluent sample whose relative composition has been determined by gamma spectrometry and found to be identical with that of the "average" effluent.

Measurement method

Place the flask on the scintillator.

Determine the response of the detector using the reference source of known total activity $A_0$ (sum of the activity of the gamma-emitting nuclides identified and determined by spectrometry) giving rise to a net count $N_0$ over a time $t_0$ (do this once a month so as to ensure that the detector response is constant).

Put the sample in position and measure the count $N$ during a time $t$.

The total gamma activity $A$ of the sample is

$$A = A_0 \frac{N/t}{N_0/t_0}$$

Measurement threshold

The sample material and the measurement time must permit a significant measurement with a reference source activity of $10^{-10}$ Ci (3.7 Bq) or a $^{137}$Cs solution having an activity of $2 \times 10^{-6}$ Ci/m$^3$ (7.4 x $10^4$ Bq/m$^3$).
Appendix 5

MEASUREMENT OF TOTAL BETA ACTIVITY
OF LIQUID EFFLUENTS

Sample

A volume of liquid depending on the specific activity, taken from a drum after stirring to ensure homogeneity or from a pipe system where the liquid is circulating.

Preparation

(a) Effluent of very low activity (specific activity less than $10^{-5}$ Ci/m$^3$ ($3.7 \times 10^5$ Bq/m$^3$) as determined by total gamma measurements)

- Acidify to 1% with pure nitric acid.
- Concentrate over a hot plate without letting it become dry.
- Transfer the concentrate by means of a Pasteur pipette to a stainless-steel capsule 54 mm in diameter.
- Evaporate to dryness without the temperature of the hot plate exceeding 60°C.
- Rinse the capsule with 2% nitric acid, pour the rinsing solution into the capsule and evaporate to dryness.
- Verify visually that the deposit is sufficiently thick. If it is not, start again with a smaller volume of effluent. Check the thickness of the deposits periodically by drying a capsule in an oven (60°C) for ten hours and then weighing it; the deposit thickness should be less than 10 mg/cm$^2$.

(b) Effluent with a specific activity greater than $10^{-5}$ Ci/m$^3$ ($3.7 \times 10^5$ Bq/m$^3$)

- Evaporate at most 10 ml of the sample directly in a stainless-steel capsule of 54 mm dia.

Note: Fixation of the contamination by a Mylar foil is preferable to the use of Fluorjet as a protection. The protective substance must be removed if the sample is to undergo alpha measurement.

Measurement method

See the method described in Appendix 2.

Measurement threshold

The sample volume and the measurement time must permit a significant measurement with effluent of a specific total beta activity of $10^{-7}$ Ci/m$^3$ ($3.7 \times 10^5$ Bq/m$^3$).
Appendix 6

MEASUREMENT OF TOTAL ALPHA ACTIVITY
OF LIQUID EFFLUENTS

Method for effluents with total beta activity $> 10^{-5} \text{Ci/m}^3$ ($> 3.7 \times 10^3 \text{Bq/m}^3$)\(^4\)

Sample

A 10 cm\(^3\) volume of liquid, taken from a drum after stirring to ensure homogeneity or from a pipe system where the liquid is circulating.

Preparation

Evaporate at most 10 cm\(^3\) of the sample directly in a stainless-steel cup, 54 mm in diameter, as described for total beta measurement.

When alpha activity is detected, one must always ensure that part of the activity is not absorbed within the deposit. For this purpose, evaporation must be carried out again, with a sample volume one tenth of the initial volume, and completed by the time the initial volume is reached by the non-active water (for a satisfactory distribution in the cup), so as to be sure that the activity found remains proportional to the volume of sample introduced into the cup.

Equipment and measurement method

These are identical to those employed in measuring total beta activity (Appendix 2), except that the detector functions as a proportional counter, with the high voltage adjusted to the detection of the alpha radiation, the reference source being a thin deposit of plutonium.

Measurement threshold

The sample volume and the measurement time must permit a significant measurement with effluent of a specific total alpha activity of $10^{-7} \text{Ci/m}^3$ ($3.7 \times 10^3 \text{Bq/m}^3$).

\(^4\) In the case of effluent with a lower activity, the evaporation of a greater quantity may lead to a deposit thickness which is inadmissible from the point of view of alpha measurement.
Appendix 7

MEASUREMENT OF TRITIUM

Sample

An amount of 30 ml from a volume of liquid, taken from a drum after stirring to ensure homogeneity or from a pipe system where the liquid is circulating.

Preparation

Distil the sample in a vacuum at low temperature. Let the distillate cool down.
Introduce 10 ml of scintillator solution (Instagel) into a plastic flask with a screw-type stopper.
Pipette 1 ml of the distillate and mix it, by stirring, with the scintillator solution.

Equipment

A liquid scintillation detector.
A reference source consisting of a homogeneous mixture of 10 ml of scintillator solution with 1 ml of a tritium solution with known activity in distilled water.
A background sample obtained by homogeneously mixing 10 ml of scintillator solution with 1 ml of distilled water.

Measurement method

Place the flask in the detector after leaving it in darkness for at least one hour and cooling the sample to the detector operation temperature.
Determine the response of the detector for the reference source \( N_1 \) with known activity \( A_0 \) and for the background sample \( N_2 \) over the same measurement time \( t_0 \).
Leave the sample to be measured in position for a time \( t \) giving a count \( N_3 \).
Determine the activity \( A \) of the sample:

\[
A = A_0 \frac{N_3 - N_2 t_0 / t}{N_1 - N_2} t_0 / t
\]

which is given in the same unit as the activity of the reference source.

Measurement threshold

The material and the measurement time must permit a significant measurement with a sample activity of \( 10^{-4} \) Ci/m\(^3\) (3.7 \times 10^6 Bq/m\(^3\)).
VENTILATION CIRCUIT OF THE FESSENHEIM NUCLEAR POWER PLANT
AND LIQUID EFFLUENT TREATMENT SYSTEMS AT CHOOZ

C = COOLER
PF = PREFILTER
AF = ABSOLUTE FILTER
CF = CHARCOAL FILTER

FIG. A2-7. Simplified diagram showing the liquid effluent treatment systems at the Chooz nuclear power plant.
SAMPLE FORMS OF MONTHLY STATEMENTS
FOR EFFLUENTS FROM NUCLEAR POWER PLANTS

Monthly statements:

- Gaseous effluents Doc. 451
- Liquid effluents Doc. 452A
- Low-activity liquid effluents\(^5\) Doc. 452B

\(^5\) General information concerning low-activity liquid effluents is entered in Doc. 452A.
### ETAT MENSUEL des EFFLUENTS RADIOACTIFS GAZEUX REJETES

**REPERAGE ORIFICE :**

<table>
<thead>
<tr>
<th>N°</th>
<th>Date</th>
<th>Heure</th>
<th>Durée (heures)</th>
<th>Volume TPN (m³)</th>
<th>Débit approximatif (m³/h)</th>
<th>(10^6 \text{Ci/m}^3) ACTIVITE VOLUMIQUE DES REJETS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Spectrométrie (\gamma)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(10^{12} \text{Ci/m}^3)</td>
</tr>
</tbody>
</table>

**REJETS PERMANENTS - VENTILATIONS**

|    |       |       |                |                 |                          | Spectrométrie \(\gamma\)                         |
|    |       |       |                |                 |                          | \(10^{12} \text{Ci/m}^3\)                       |

**REJETS TEMPORAIRES - VIDANGES**

|    |       |       |                |                 |                          | Spectrométrie \(\gamma\)                         |
|    |       |       |                |                 |                          | \(10^{12} \text{Ci/m}^3\)                       |

**REJETS PERMANENTS - VENTILATIONS**

<table>
<thead>
<tr>
<th>N°</th>
<th>Date</th>
<th>Heure</th>
<th>Durée (heures)</th>
<th>Volume TPN (m³)</th>
<th>Débit approximatif (m³/h)</th>
<th>Vol. Gazeux (Ci/m³)</th>
<th>Aérosols 10⁻²</th>
<th>Rejetée 10⁻²</th>
</tr>
</thead>
</table>

**TOTAL ou moyenne du mois**

**VENT moyen**

**REJETS TEMPORAIRES - VIDANGES**

|    |       |       |                |                 |                          | Spectrométrie \(\gamma\)                         |
|    |       |       |                |                 |                          | \(10^{12} \text{Ci/m}^3\)                       |

**TOTAL ou moyenne**

**TOTAL général du mois**
# ETAT MENSUEL des EFFLUENTS RADIOACTIFS LIQUIDES REJETES

## 1. ACTIVITÉ VOLUMIQUE DES REJETS (10^6 Ci/m³) Spectrométrie γ

<table>
<thead>
<tr>
<th>N°</th>
<th>α</th>
<th>β</th>
<th>90Sr</th>
<th>3H</th>
</tr>
</thead>
</table>

**EFFLUENTS FORTEMENT RADIOACTIFS**

**EFFLUENTS FAIBLEMENT RADIOACTIFS** (échantillon mensuel)

## 2. REJETS

<table>
<thead>
<tr>
<th>N°</th>
<th>Date</th>
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<th>Durée (heure)</th>
<th>Volume (m³)</th>
<th>Débit (m³/hr)</th>
<th>Débit (m³/s)</th>
<th>Date transmission</th>
<th>vCPR</th>
<th>SCPRI</th>
<th>Activité β (10^6 Ci/m³)</th>
<th>Activité 3H (Ci)</th>
</tr>
</thead>
</table>

**EFFLUENTS FORTEMENT RADIOACTIFS**

**EFFLUENTS FAIBLEMENT RADIOACTIFS** (report de l’état correspondant)

**TOTAL MOYENNE DU MOIS**

## 3. ACTIVITÉ TOTALE REJETEE

<table>
<thead>
<tr>
<th>Unité : Ci</th>
<th>α</th>
<th>β</th>
<th>90Sr</th>
<th>3H</th>
</tr>
</thead>
</table>

Valeur du mois

Cumulée annuelle

*Nota : il n’a été ajouté ni Radium 226 ni Radium 228*

Visa du chef de centrale
<table>
<thead>
<tr>
<th>N°</th>
<th>Date début rejet</th>
<th>Heure</th>
<th>Durée (heure)</th>
<th>Volume (m³)</th>
<th>Débit (m³/s)</th>
<th>Débit volumique (10³ Ci/m³)</th>
<th>rejet volumique (10³ Ci)</th>
<th>rejet volumique &lt;10³ Ci/m³</th>
<th>OBSERVATIONS</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL OU MOYENNE**

Viss du chef de centrale
MONITORING OF RELEASES FROM AN IRRADIATED FUEL REPROCESSING PLANT

L. Fitoussi, France

GENERAL DESCRIPTION

At its UP 2 plant, the La Hague facility reprocesses irradiated fuel by the PUREX process. The fuel stems from graphite/gas, natural-uranium reactors and pressurized or boiling water enriched-uranium reactors.

The reprocessing operations are carried out at three groups of workshops:

- A high-activity group;
- An intermediate-activity group;
- A fission-product storage group.

The gaseous effluents from the various groups of workshops are collected and purified by high-efficiency washing and filtration. After purification the gas stream is discharged into the atmosphere by a single stack, 100 m high and 6 m in diameter, located at a high point on the site (184 m).

The radionuclides released into the air are: krypton-85, iodine-129 and -131, and tritium.

The liquid effluents are collected in the workshops by drainage systems, which transfer them to the effluent treatment station in the case of active or suspect solutions. Active solutions undergo treatment by chemical and physical processes.

After purification the waste water is released into the sea by an underwater drainage system 5 km long, which brings the outlet point into the middle of a tidal current 2 km offshore.

The radionuclides contained in the purified waste water are fission products originating from irradiated fuels in only slightly variable proportions, in which ruthenium-rhodium-106 predominates. Traces of the transuranium elements are also found in these solutions.

MONITORING SYSTEM

Releases into the air

The releases into the air from each workshop are continuously monitored during their transfer to the main collector stream.
Abnormalities detected at this stage result in feed-back to the treatment process. The main stream passes a monitoring point immediately before release into the atmosphere. Figure A2—8 is a schematic representation of the circulation of gaseous effluents and indicates the site of the monitoring points.

**Releases into the sea**

All the radioactive effluents from the UP 2 industrial complex are collected from the workshop tanks. After analysis they are transferred by drainage systems to the effluent treatment station. The effluents are graded in three groups for purposes of treatment to remove the radioactive elements.

After treatment the effluents are divided into two categories of radioactive waste water.

These solutions are stored in tanks for sampling and analysis before authorization for release.

Figure A2—9 represents schematically the circulation of the liquid effluents and indicates the site of the monitoring points.
SAMPLING TECHNIQUES

Releases into the air

Gas is continuously sampled at various monitoring points, either by a pumping system or by a negative-pressure device. The sample stream passes successively through continuous measurement instruments and continuous sampling traps.

Releases into the sea

Solutions for which an application for authorization of the release has to be made are continuously sampled during filling of the tank; also, samples are taken at three levels of the filled tank.

MEASURING TECHNIQUES

Releases into the air

The monitoring system for gaseous effluents contains the following components, located in two monitoring lines.
Continuous sampling and measurement line

(a) Measurement of beta radioactivity by scintillation detector, and measurement of dust samples taken on fixed or mobile filters (with alarm system);
(b) Measurement of krypton-85 by circulating-gas ionization chamber;
(c) Gamma spectrometric measurement of the iodine-131 activity of samples taken by absorption on activated charcoal (with alarm system).

Continuous sampling and discontinuous measurement line

(a) Sampling of dust on fixed filters; measurement of alpha and beta activity with a low-background instrument and gamma spectrometry in the laboratory;
(b) Sampling of iodine on activated charcoal; measurement of iodine-131 and iodine-129 activity by gamma spectrometry in the laboratory;
(c) Sampling of oxidized tritium in a bubble flask, and sampling of tritium gas after oxidation in a bubble flask; laboratory measurement by the liquid scintillation technique.

Releases into the sea

The radioactivity of the liquid effluents is monitored in the laboratory. The following determinations are made for each sample:

Gross alpha activity measurement with a scintillation detector;
Gross beta activity measurement with a circulating-gas windowless detector;
Measurement of radioactivity due to tritium after distillation with a liquid scintillation counter;
Gamma spectrometric measurement of radionuclides:
  Ruthenium-rhodium-103; ruthenium-rhodium-106; caesium-134;
  caesium-barium-137; cerium-praseodymium-141;
  cerium-praseodymium-144; zirconium-95; niobium-95; antimony;
  cobalt-60.
Radiochemical measurement of strontium-89 and strontium-90/yttrium-90;
Radiochemical measurement of transuranium elements; pH measurement;
Dry-residue measurement;
Verification to ensure the absence of insoluble matter;
Radiochemical determination on mean monthly sample of zinc-65 and silver-110 plus silver-110 m).
SENSITIVITY OF MEASUREMENTS

Releases into the air

<table>
<thead>
<tr>
<th>Continuous measurement:</th>
<th>Ci/m³</th>
<th>Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radioactivity of dusts</td>
<td>$10^{-12}$</td>
<td>$3.7 \times 10^{-2}$</td>
</tr>
<tr>
<td>Radioactivity due to krypton-85</td>
<td>$10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Discontinuous measurement:</th>
<th>Ci/m³</th>
<th>Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha radioactivity of dust</td>
<td>$10^{-14}$</td>
<td>$3.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Beta radioactivity of dust</td>
<td>$10^{-14}$</td>
<td>$3.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Radioactivity due to iodine-131</td>
<td>$10^{-14}$</td>
<td>$3.7 \times 10^{-4}$</td>
</tr>
<tr>
<td>Radioactivity due to iodine-129</td>
<td>$10^{-12}$</td>
<td>$3.7 \times 10^{-2}$</td>
</tr>
<tr>
<td>Radioactivity due to tritium</td>
<td>$10^{-9}$</td>
<td>$3.7 \times 10^{1}$</td>
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Releases into the sea

<table>
<thead>
<tr>
<th></th>
<th>Ci/m³</th>
<th>Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross alpha radioactivity</td>
<td>$10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Gross beta radioactivity</td>
<td>$10^{-5}$</td>
<td>$3.7 \times 10^{5}$</td>
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<tr>
<td>Radioactivity due to tritium</td>
<td>$10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Radioactivity of gamma emitters by spectrometry of mixtures</td>
<td>$10^{-4}$</td>
<td>$3.7 \times 10^{6}$</td>
</tr>
<tr>
<td>Radioactivity due to strontium-yttrium-90</td>
<td>$10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Radioactivity due to strontium-89</td>
<td>$10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
<tr>
<td>Radioactivity due to transuranium elements</td>
<td>$10^{-6}$</td>
<td>$3.7 \times 10^{4}$</td>
</tr>
</tbody>
</table>
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### Annex 3

**REPORTING OF RESULTS**

**UNITED STATES REGULATORY GUIDE 1.21**

Effluent and waste disposal report

**TABLE A3-I. EFFLUENT AND WASTE DISPOSAL SEMIANNUAL REPORT (YEAR)**

**GASEOUS EFFLUENTS – SUMMATION OF ALL RELEASES**

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Quarter</th>
<th>Quarter</th>
<th>Est. Total Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Fission &amp; activation gases</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total release</td>
<td>Ci</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>2. Average release rate for period</td>
<td>µCi/s</td>
<td>E</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>3. Percent of Technical specification limit</td>
<td>%</td>
<td>E</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td><strong>B. Iodines</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total iodine-131</td>
<td>Ci</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>2. Average release rate for period</td>
<td>µCi/s</td>
<td>E</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>3. Percent of technical specification limit</td>
<td>%</td>
<td>E</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td><strong>C. Particulates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Particulates with half-lives &gt;8 days</td>
<td>Ci</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>2. Average release rate for period</td>
<td>µCi/s</td>
<td>E</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>3. Percent of technical specification limit</td>
<td>%</td>
<td>E</td>
<td>E</td>
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</tr>
<tr>
<td>4. Gross alpha radioactivity</td>
<td>Ci</td>
<td>E</td>
<td>E</td>
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<tr>
<td><strong>D. Tritium</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>1. Total release</td>
<td>Ci</td>
<td>E</td>
<td>E</td>
<td>E</td>
</tr>
<tr>
<td>2. Average release rate for period</td>
<td>µCi/s</td>
<td>E</td>
<td>E</td>
<td></td>
</tr>
<tr>
<td>3. Percent of technical specification limit</td>
<td>%</td>
<td>E</td>
<td>E</td>
<td></td>
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</table>

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### TABLE A3-II. EFFLUENT AND WASTE DISPOSAL SEMIANNUAL REPORT (YEAR)
#### GASEOUS EFFLUENTS – ELEVATED RELEASE

<table>
<thead>
<tr>
<th>Nuclides Released</th>
<th>Continuous Mode</th>
<th>Batch Mode</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>Quarter</td>
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<tr>
<td><strong>1. Fission gases</strong></td>
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<td></td>
</tr>
<tr>
<td>krypton-85m</td>
<td>Ci</td>
<td>. E</td>
</tr>
<tr>
<td>krypton-87</td>
<td>Ci</td>
<td>. E</td>
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<tr>
<td>krypton-88</td>
<td>Ci</td>
<td>. E</td>
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<tr>
<td>xenon-135</td>
<td>Ci</td>
<td>. E</td>
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<tr>
<td>xenon-135m</td>
<td>Ci</td>
<td>. E</td>
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<tr>
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<td>. E</td>
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<tr>
<td>Total for period</td>
<td>Ci</td>
<td>. E</td>
</tr>
<tr>
<td><strong>2. Iodines</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>iodine-133</td>
<td>Ci</td>
<td>. E</td>
</tr>
<tr>
<td>iodine-135</td>
<td>Ci</td>
<td>. E</td>
</tr>
<tr>
<td>Total for period</td>
<td>Ci</td>
<td>. E</td>
</tr>
<tr>
<td><strong>3. Particulates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cesium-134</td>
<td>Ci</td>
<td>. E</td>
</tr>
<tr>
<td>cesium-137</td>
<td>Ci</td>
<td>. E</td>
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<tr>
<td>unidentified</td>
<td>Ci</td>
<td>. E</td>
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This publication is no longer valid
Please see http://www.ns-iaea.org/standards/
### TABLE A3-III. EFFLUENT AND WASTE DISPOSAL SEMIANNUAL REPORT (YEAR)

#### GASEOUS EFFLUENTS – GROUND-LEVEL RELEASES

<table>
<thead>
<tr>
<th>Nuclides Released</th>
<th>CONTINUOUS MODE</th>
<th>BATCH MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>Quarter</td>
</tr>
<tr>
<td>1. Fission gases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>krypton-85</td>
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<td>E</td>
</tr>
<tr>
<td>krypton-85m</td>
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<tr>
<td>krypton-87</td>
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<td>Ci</td>
<td>E</td>
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<tr>
<td>xenon-133</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>xenon-135</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>xenon-135m</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>xenon-138</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>Others (specify)</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>unidentified</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>Total for period</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>2. Iodines</td>
<td></td>
<td></td>
</tr>
<tr>
<td>iodine-131</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>iodine-133</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>iodine-135</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>Total for period</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>3. Particulates</td>
<td></td>
<td></td>
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<tr>
<td>strontium-89</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>strontium-90</td>
<td>Ci</td>
<td>E</td>
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<td>E</td>
</tr>
<tr>
<td>cesium-137</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>barium-lanthanum-140</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>Others (specify)</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>unidentified</td>
<td>Ci</td>
<td>E</td>
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<tr>
<td>Unit</td>
<td>Quarter</td>
<td>Quarter</td>
</tr>
<tr>
<td>------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>A. Fission and activation products</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total release (not including tritium, gases, alpha)</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>2. Average diluted concentration during period</td>
<td>μCi/ml</td>
<td>E</td>
</tr>
<tr>
<td>3. Percent of applicable limit</td>
<td>%</td>
<td>E</td>
</tr>
<tr>
<td>B. Tritium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total release</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>2. Average diluted concentration during period</td>
<td>μCi/ml</td>
<td>E</td>
</tr>
<tr>
<td>3. Percent of applicable limit</td>
<td>%</td>
<td>E</td>
</tr>
<tr>
<td>C. Dissolved and entrained gases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total release</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>2. Average diluted concentration during period</td>
<td>μCi/ml</td>
<td>E</td>
</tr>
<tr>
<td>3. Percent of applicable limit</td>
<td>%</td>
<td>E</td>
</tr>
<tr>
<td>D. Gross alpha radioactivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Total release</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>E. Volume of waste released (prior to dilution)</td>
<td>liters</td>
<td>E</td>
</tr>
<tr>
<td>F. Volume of dilution water used during period</td>
<td>liters</td>
<td>E</td>
</tr>
</tbody>
</table>
TABLE A3-V. EFFLUENT AND WASTE DISPOSAL SEMIANNUAL REPORT (YEAR)
LIQUID EFFLUENTS

<table>
<thead>
<tr>
<th>Nuclides Released</th>
<th>CONTINUOUS MODE</th>
<th>BATCH MODE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit</td>
<td>Quarter</td>
</tr>
<tr>
<td>strontium-89</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>strontium-90</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>cesium-134</td>
<td>Ci</td>
<td>E</td>
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<tr>
<td>cesium-137</td>
<td>Ci</td>
<td>E</td>
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<tr>
<td>iodine-131</td>
<td>Ci</td>
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<tr>
<td>cobalt-58</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>cobalt-60</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>iron-59</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>zinc-65</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>manganese-54</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>chromium-51</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>zirconium-niobium-95</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>molybdenum-99</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>technetium-99m</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>barium-lanthanum-140</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>cerium-141</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>Other (specify)</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td></td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
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<td>E</td>
</tr>
<tr>
<td></td>
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<td>E</td>
</tr>
<tr>
<td>unidentified</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>Total for period (above)</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>xenon-133</td>
<td>Ci</td>
<td>E</td>
</tr>
<tr>
<td>xenon-135</td>
<td>Ci</td>
<td>E</td>
</tr>
</tbody>
</table>
### A. SOLID WASTE SHIPPED OFFSITE FOR BURIAL OR DISPOSAL (Not irradiated fuel)

<table>
<thead>
<tr>
<th>1. Type of waste</th>
<th>Unit</th>
<th>6-month Period</th>
<th>Est. Total Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Spent resins, filter sludges, evaporator bottoms, etc.</td>
<td>m³</td>
<td>. E</td>
<td>. E</td>
</tr>
<tr>
<td>b. Dry compressible waste, contaminated equip, etc.</td>
<td>Ci</td>
<td>. E</td>
<td>. E</td>
</tr>
<tr>
<td>c. Irradiated components, control rods, etc.</td>
<td>m³</td>
<td>. E</td>
<td>. E</td>
</tr>
<tr>
<td>d. Other (describe)</td>
<td>Ci</td>
<td>. E</td>
<td>. E</td>
</tr>
</tbody>
</table>

### 2. Estimate of major nuclide composition (by type of waste)

<table>
<thead>
<tr>
<th>a.</th>
<th>%</th>
<th>. E</th>
</tr>
</thead>
<tbody>
<tr>
<td>b.</td>
<td>%</td>
<td>. E</td>
</tr>
<tr>
<td>c.</td>
<td>%</td>
<td>. E</td>
</tr>
<tr>
<td>d.</td>
<td>%</td>
<td>. E</td>
</tr>
</tbody>
</table>

### 3. Solid Waste Disposition

<table>
<thead>
<tr>
<th>Number of Shipments</th>
<th>Mode of Transportation</th>
<th>Destination</th>
</tr>
</thead>
</table>

### B. IRRADIATED FUEL SHIPMENTS (Disposition)

<table>
<thead>
<tr>
<th>Number of Shipments</th>
<th>Mode of Transportation</th>
<th>Destination</th>
</tr>
</thead>
</table>
**TABLE A3-VII. HOURS AT EACH WIND SPEED AND DIRECTION**

**PERIOD OF RECORD:**

**STABILITY CLASS:**

**ELEVATION:**

<table>
<thead>
<tr>
<th>Wind Direction</th>
<th>1-3</th>
<th>4-7</th>
<th>8-12</th>
<th>13-18</th>
<th>19-24</th>
<th>&gt;24</th>
<th>TOTAL</th>
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<tr>
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</tbody>
</table>

**VARIABLE**

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Periods of calm (hours):</th>
<th>Hours of missing data:</th>
</tr>
</thead>
</table>

*In the table, record the total number of hours of each category of wind direction for each calendar quarter. Provide similar tables separately for each atmospheric stability class and elevation.*
**TABLE A3-VIII. CLASSIFICATION OF ATMOSPHERIC STABILITY**

<table>
<thead>
<tr>
<th>Stability Classification</th>
<th>Pasquill Categories</th>
<th>$\sigma^a$ (degrees)</th>
<th>Temperature change with height (°C/100m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely unstable</td>
<td>A</td>
<td>25.0</td>
<td>$&lt;-1.9$</td>
</tr>
<tr>
<td>Moderately unstable</td>
<td>B</td>
<td>20.0</td>
<td>-1.9 to -1.7</td>
</tr>
<tr>
<td>Slightly unstable</td>
<td>C</td>
<td>15.0</td>
<td>-1.7 to -1.5</td>
</tr>
<tr>
<td>Neutral</td>
<td>D</td>
<td>10.0</td>
<td>-1.5 to -0.5</td>
</tr>
<tr>
<td>Slightly stable</td>
<td>E</td>
<td>5.0</td>
<td>-0.5 to 1.5</td>
</tr>
<tr>
<td>Moderately stable</td>
<td>F</td>
<td>2.5</td>
<td>1.5 to 4.0</td>
</tr>
<tr>
<td>Extremely stable</td>
<td>G</td>
<td>1.7</td>
<td>$&gt;4.0$</td>
</tr>
</tbody>
</table>

$^a$ Standard deviation of horizontal wind direction fluctuation over a period of 15 minutes to 1 hour. The values shown are average for each stability classification.
UNITED STATES EFFLUENT INFORMATION SYSTEM (EIS) and ON-SITE DISCHARGE INFORMATION SYSTEMS (ODIS)

Input forms (ERDA Form 789)
**INVENTORY REPORT**

**CODE IDENT.**

<table>
<thead>
<tr>
<th>Effluent Disch. No.</th>
<th>Point Iden.</th>
</tr>
</thead>
</table>

**REPORT PERIOD**

<table>
<thead>
<tr>
<th>FROM</th>
<th>TO</th>
</tr>
</thead>
</table>

**SECURITY CLASSIFICATION**

<table>
<thead>
<tr>
<th>DATA DESIGNATION</th>
<th>AREA CODE</th>
</tr>
</thead>
</table>

**MONITORING SYSTEM**

<table>
<thead>
<tr>
<th>NO. OF SAMPLES</th>
<th>NAME OF RECEIVING MEDIA OR STORAGE/DISPOSAL</th>
</tr>
</thead>
</table>

**OPERATIONS GENERATING POLLUTANTS**

| NARRATIVE SUMMARY OF ERDA FORM 789 |

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CONVERSION TABLE:

FACTORS FOR CONVERTING SOME OF THE MORE COMMON UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI) EQUIVALENTS

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Column 2</th>
<th>Column 3</th>
<th>Column 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiply data given in:</td>
<td>by:</td>
<td>to obtain data in:</td>
<td></td>
</tr>
<tr>
<td><strong>Radiation units</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>▪ becquerel</td>
<td>1 Bq</td>
<td>(has dimensions of s⁻¹)</td>
<td></td>
</tr>
</tbody>
</table>
| ▪ disintegrations per second (= d/s/s) | 1 s⁻¹ | = 1.00 X 10⁶ Bq | *
| ▪ curie | 1 Ci | = 3.70 X 10¹⁰ Bq | *
| ▪ roentgen | 1 R | = 2.58 X 10⁻⁴ C/kg | *
| ▪ gray | 1 Gy | = 1.00 X 10² J/kg | *
| ▪ rad | 1 rad | = 1.00 X 10⁻² Gy | *
| ▪ sievert (radiation protection only) | 1 Sv | = 1.00 X 10⁰ J/kg | *
| ▪ rem (radiation protection only) | 1 rem | = 1.00 X 10⁻² J/kg | *

**Mass**

| ▪ unified atomic mass unit (¹/₁₂ of the mass of ¹²C) | 1 u | = 1.660 57 X 10⁻²³ kg, approx. |
| ▪ tonne (= metric ton) | 1 t | = 1.00 X 10³ kg | *
| ▪ pound mass (avoirdupois) | 1 lbm | = 4.536 X 10⁻³ kg |
| ▪ ounce mass (avoirdupois) | 1 ozm | = 2.835 X 10⁻² g |
| ▪ ton (long) (= 2240 lbm) | 1 ton | = 1.016 X 10³ kg |
| ▪ ton (short) (= 2000 lbm) | 1 short ton | = 9.072 X 10² kg |

**Length**

| ▪ statute mile | 1 mile | = 1.609 X 10⁰ km |
| ▪ nautical mile (international) | 1 n mile | = 1.852 X 10⁰ km | *
| ▪ yard | 1 yd | = 9.144 X 10⁻² m | *
| ▪ foot | 1 ft | = 3.048 X 10⁻² m | *
| ▪ inch | 1 in | = 2.54 X 10⁻² mm | *
| ▪ mil (= 10⁻³ in) | 1 mil | = 2.54 X 10⁻² mm | *

**Area**

| ▪ hectare | 1 ha | = 1.00 X 10⁴ m² | *
| ▪ barn (effective cross-section, nuclear physics) | 1 b | = 1.00 X 10⁻²⁸ m² | *
| ▪ square mile, (statute mile)² | 1 mile² | = 2.590 X 10⁶ km² |
| ▪ acre | 1 acre | = 4.047 X 10² m² |
| ▪ square yard | 1 yd² | = 8.361 X 10⁻² m² |
| ▪ square foot | 1 ft² | = 9.290 X 10⁻² m² |
| ▪ square inch | 1 in² | = 6.452 X 10⁻⁴ mm² |

**Volume**

| ▪ litre | 1 l or 1 ltr | = 1.00 X 10⁻³ m³ | *
| ▪ cubic yard | 1 yd³ | = 7.646 X 10⁻³ m³ |
| ▪ cubic foot | 1 ft³ | = 2.832 X 10⁻² m³ |
| ▪ cubic inch | 1 in³ | = 1.639 X 10⁻⁵ mm³ |
| ▪ gallon (imperial) | 1 gal | = 4.546 X 10⁻³ m³ |
| ▪ gallon (U.S. liquid) | 1 gal (US) | = 3.785 X 10⁻³ m³ |

**Velocity, acceleration**

| ▪ foot per second (= fps) | 1 ft/s | = 3.048 X 10⁻¹ m/s | *
| ▪ foot per minute | 1 ft/min | = 5.08 X 10⁻² m/s | *
| ▪ mile per hour (= mph) | 1 mile/h | = 1.609 X 10⁰ km/h |
| ▪ knot (international) | 1 knot | = 1.852 X 10⁰ km/h | *
| ▪ free fall, standard, g | 1 m/s² | = 9.807 X 10⁻² m/s² |
| ▪ foot per second squared | 1 ft/s² | = 3.048 X 10⁻¹ m/s² | *

This table has been prepared by E.R.A. Beck for use by the Division of Publications of the IAEA. While every effort has been made to ensure accuracy, the Agency cannot be held responsible for errors arising from the use of this table.
### Multiply data given in: Column 3 by: Column 4 to obtain data in:

<table>
<thead>
<tr>
<th>Density, volumetric rate</th>
<th>Density, volumetric rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>pound mass per cubic inch</td>
<td>1 ( \text{lbm/m}^3 ) = 2.768 ( \times 10^4 ) ( \text{kg/m}^3 )</td>
</tr>
<tr>
<td>pound mass per cubic foot</td>
<td>1 ( \text{lbm/ft}^3 ) = 1.602 ( \times 10^1 ) ( \text{kg/m}^3 )</td>
</tr>
<tr>
<td>cubic feet per second</td>
<td>1 ( \text{ft}^3/\text{s} ) = 2.832 ( \times 10^{-2} ) ( \text{m}^3/\text{s} )</td>
</tr>
<tr>
<td>cubic feet per minute</td>
<td>1 ( \text{ft}^3/\text{min} ) = 4.719 ( \times 10^{-4} ) ( \text{m}^3/\text{s} )</td>
</tr>
</tbody>
</table>

### Force

- newton: \( 1 \text{ N} \) = \( 1.00 \times 10^0 \) \( \text{m} \cdot \text{kg} \cdot \text{s}^{-2} \) *
- dyne: \( 1 \text{ dyn} \) = \( 1.00 \times 10^{-5} \) \( \text{N} \) *
- kilogram force (= kilopond (kp)): \( 1 \text{ kgf} \) = \( 9.807 \times 10^0 \) \( \text{N} \)
- poundal: \( 1 \text{ pdl} \) = \( 1.383 \times 10^{-2} \) \( \text{N} \)
- pound force (avoirdupois): \( 1 \text{ lbf} \) = \( 4.448 \times 10^0 \) \( \text{N} \)
- ounce force (avoirdupois): \( 1 \text{ ozf} \) = \( 2.780 \times 10^{-3} \) \( \text{N} \)

### Pressure, stress

- pascal: \( 1 \text{ Pa} \) = \( 1.00 \times 10^0 \) \( \text{N/m}^2 \) *
- atmosphere, standard: \( 1 \text{ atm} \) = \( 1.01325 \times 10^5 \) \( \text{Pa} \)
- bar: \( 1 \text{ bar} \) = \( 1.00 \times 10^5 \) \( \text{Pa} \)
- centimetres of mercury (0°C): \( 1 \text{ cmHg} \) = \( 1.333 \times 10^3 \) \( \text{Pa} \)
- dyne per square centimetre: \( 1 \text{ dyn/cm}^2 \) = \( 1.00 \times 10^{-1} \) \( \text{Pa} \)
- feet of water (4°C): \( 1 \text{ ftH}_{20} \) = \( 2.989 \times 10^3 \) \( \text{Pa} \)
- inches of mercury (0°C): \( 1 \text{ inHg} \) = \( 3.386 \times 10^3 \) \( \text{Pa} \)
- inches of water (4°C): \( 1 \text{ inH}_{20} \) = \( 2.491 \times 10^2 \) \( \text{Pa} \)
- kilogram force per square centimetre: \( 1 \text{ kgf/cm}^2 \) = \( 9.807 \times 10^4 \) \( \text{Pa} \)
- pound force per square foot: \( 1 \text{ lbf/ft}^2 \) = \( 4.788 \times 10^1 \) \( \text{Pa} \)
- pound force per square inch (= psi): \( 1 \text{ lbf/in}^2 \) = \( 6.895 \times 10^2 \) \( \text{Pa} \)
- torr (0°C) (= mmHg): \( 1 \text{ torr} \) = \( 1.333 \times 10^2 \) \( \text{Pa} \)

### Energy, work, quantity of heat

- joule: \( 1 \text{ J} \) = \( 1.00 \times 10^0 \) \( \text{N} \cdot \text{m} \)
- electronvolt: \( 1 \text{ eV} \) = \( 1.60219 \times 10^{-19} \) \( \text{J} \), approx.
- British thermal unit (International Table): \( 1 \text{ Btu} \) = \( 1.055 \times 10^3 \) \( \text{J} \)
- calorie (thermochemical): \( 1 \text{ cal} \) = \( 4.184 \times 10^0 \) \( \text{J} \)
- calorie (International Table): \( 1 \text{ cal}_{\text{IT}} \) = \( 4.187 \times 10^0 \) \( \text{J} \)
- erg: \( 1 \text{ erg} \) = \( 1.00 \times 10^{-7} \) \( \text{J} \)
- foot-pound force: \( 1 \text{ ft-lbf} \) = \( 1.356 \times 10^0 \) \( \text{J} \)
- kilowatt-hour: \( 1 \text{ kWh} \) = \( 3.60 \times 10^6 \) \( \text{J} \)
- kiloton explosive yield (PNE) (\( \equiv 10^{12} \text{ g-cal} \)): \( 1 \text{ kt yield} \) = \( 4.2 \times 10^{12} \) \( \text{J} \)

### Power, radiant flux

- watt: \( 1 \text{ W} \) = \( 1.00 \times 10^0 \) \( \text{J/s} \)
- British thermal unit (International Table) per second: \( 1 \text{ Btu/s} \) = \( 1.055 \times 10^3 \) \( \text{W} \)
- calorie (International Table) per second: \( 1 \text{ cal/s} \) = \( 4.187 \times 10^0 \) \( \text{W} \)
- foot-pound force/second: \( 1 \text{ ft-lbf/s} \) = \( 1.356 \times 10^0 \) \( \text{W} \)
- horsepower (electric): \( 1 \text{ hp} \) = \( 7.46 \times 10^2 \) \( \text{W} \)
- horsepower (metric) (= ps): \( 1 \text{ ps} \) = \( 7.355 \times 10^2 \) \( \text{W} \)
- horsepower (550 ft-lb/s): \( 1 \text{ hp} \) = \( 7.457 \times 10^2 \) \( \text{W} \)

### Temperature

\[ t = T - T_0 \]

where \( T \) is the thermodynamic temperature in kelvin and \( T_0 \) is defined as 273.15 K

- degree Fahrenheit: \( t_{F} = \frac{9}{5} t_{C} + 32 \)
- degree Rankine: \( t_{R} = \frac{9}{5} t_{C} + 490 \)
- degrees of temperature difference: \( \Delta T_{\text{R}} = \Delta t_{\text{C}} \)

### Thermal conductivity

\[ 1 \text{ Btu/in}(\text{ft}^2 \cdot \text{s} \cdot \text{°F}) (\text{International Table Btu}) = 5.192 \times 10^2 \text{ W m}^{-1} \cdot \text{K}^{-1} \]
\[ 1 \text{ Btu/(ft} \cdot \text{s} \cdot \text{°F}) (\text{International Table Btu}) = 6.231 \times 10^3 \text{ W m}^{-1} \cdot \text{K}^{-1} \]
\[ 1 \text{ cal} /\text{cm} \cdot \text{s} \cdot \text{°C} = 4.187 \times 10^7 \text{ W m}^{-1} \cdot \text{K}^{-1} \]

\( a \) atm abs, ata; atmospheres absolute; \( b \) lbf/in\(^2\) (g) (= psig): gauge pressure; atm (g), atu: atmospheres gauge. \( b \) lbf/in\(^2\) abs (= psia): absolute pressure.

\( c \) The abbreviation for temperature difference, \( \deg = \degK = \degC \), is no longer acceptable as an SI unit.
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