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# SOURCE AND ENVIRONMENTAL MONITORING FOR RADIATION PROTECTION OF THE PUBLIC

Draft Document

# FOREWORD

Radiation monitoring is an essential requirement in the framework of radiation protection. Only monitoring can provide actual data on radioactive concentrations in effluents and in the environment, and on dose rates. It can also be used to demonstrate compliance with authorized limits and provide data to aid optimization of radiation protection. Detailed guidance on monitoring related to radiation protection of the public was last published by the IAEA in 1975 as Safety Series No. 41 entitled "Objectives and Design of Environmental Monitoring Programmes for Radioactive Contaminants." Much of that advice is still valid. However, it deals with environmental monitoring relevant only to releases of radionuclides from nuclear installations.

The public is exposed to radiation from many other sources, some of which are more significant. The International Commission on Radiological Protection (ICRP) issued its Publication 39 "Principles for Limiting Exposure of the Public to Natural Sources of Radiation" in 1984 for developing its guidance on natural radiation. In 1985, the ICRP published guidance on, "Principles of Monitoring for the Radiation Protection of the Population" as Publication 43 and in 1991 published the "1990 Recommendations of the International commission on Radiological Protection as Publication 60. On the basis of the 1990 recommendations of the ICRP, the new *International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources* was finalized in 1996 and was jointly sponsored by the following organizations: The Food and Agricultural Organization of the United Nations (FAO), the International Atomic Energy Agency (IAEA), the International Labour Organization (ILO), the Nuclear Energy Agency of the Organization for Labour Organization (OECD/NEA), the Pan American Health Organization (PAHO) and the World Health Organization (WHO). As part of the RADWASS program, IAEA has also published a document on the "Principles of Radioactive Waste Management," which was also useful in the development of this Guide.

As a result of these developments, this Guide is the revision of Safety Series No. 41 and has been expanded to its scope to account for the conceptual change of radiation protection as well as relevant developments in instruments and methodology. The present Guide describes both the principles and the practice of monitoring for radiation protection of the public under

the normal exposure conditions. It is categorized as a Safety Guide in the hierarchy of the IAEA Safety Series Publications.

The present Guide was prepared with the help of Advisory Group[illegible]der the chairmanship of Z. Jaworowski and _____. F. Morley was consultant to the first Advisory Group meeting, F. Fry for the second and the third meetings, and C. Jones and S. Krishnamony for the fourth meeting. The IAEA gratefully acknowledges all those who took part in preparation of this Guide.

Final technical editing was carried out by Y. Inoue and _____, to ensure consistency with the IAEA Basic Safety Standards Publication No. 115 in 1996. The resulting document was circulated and reviewed among all participants and then revised to obtain international consensus.

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# 1. INTRODUCTION

## 1.1 BACKGROUND

101. Everyone in the world is exposed to radiation from various sources, natural and artificial. Many reports have been published on the assessment of doses received from these sources [1,2]. Natural radiation usually contributes the largest fraction of the total exposure to humans. Any system of radiological protection must take into account all significant radiation sources. The International Commission on Radiological Protection (ICRP) Report No. 60, as well as the IAEA Basic Safety Standards (BSS) Safety Series No. 115 establish basic requirements for protection against the risks associated with exposure to ionizing radiation (hereinafter termed radiation) [3,4]. This may include normal and potential exposures to occupational workers, to patients undergoing medical diagnosis or treatment, and to members of the pubic who may receive radiation exposure by a *practice* or by *intervention*. These exposures are divided into: *occupational exposures* which are received at the workplace and result from exposure to radiation or radioactive sources at work; *medical exposures* which are principally received by patients as a result of medical treatment or diagnosis; and *public exposures* which comprise all other exposures.

The public can be exposed to radiation from various sources, both natural and artificial. The BSS establishes basic requirements for radiological protection of the public from both of these sources of exposure and requires that *registrants and licensees be responsible for the establishment, implementation, and maintenance of appropriate monitoring equipment and surveillance programmes to assess public exposure to the satisfaction of the Regulatory Authority [BSS p. 57]*. The IAEA RADWASS document entitled, "The Principles of Radioactive Waste Management" requires that when radioactive substances may be released within authorized limits as a legitimate practice into air, water or soil, appropriate safety and control measures should be defined. In addition, *adequate records of these surveillance and monitoring [BSS p. 58]* from these programs are also required to be maintained.

102. Dose limits and constraints for radiation protection of the public are contained in ICRP Publication 60 [4] and the IAEA Basic Safety Standards. Further guidance on limiting doses to the public is contained in Safety Series No. 77, 89, 92 [6-8].

103. Radiation protection of the public is based on the system of radiological protection recommended by the ICRP. ICRP distinguishes between a "practice", which causes exposures to radiation, and "intervention", which decreases exposures. The system of radiological protection for practices is based on the three principles of justification of a practice, optimization of protection, and compliance with dose limits and constraints. Protection of the public is mainly achieved by control of sources of exposure. Monitoring provides a means of assessing the radiation exposure of population groups, critical groups and individual members of the public; the assessed doses can be used for optimization purposes and to demonstrate compliance with dose limits or constraints. Thus monitoring is an important tool for those who are responsible for ensuring that there is adequate control of practices which give rise to radiation exposure of the public.

## 1.2 OBJECTIVES

104. This Guide sets out the basic principles and methodology of monitoring for the radiation protection of the public.

105. The Guide is intended primarily for use by regulatory authorities who have responsibilities relevant to radiation protection of the public. It may also be useful to registrants or licensees of nuclear installations and others who need information on the subject. Practices in one country may lead to radiation exposure in another and in such cases the application of the relevant principles may require international cooperation.

## 1.3 SCOPE

106. This Guide describes radiation monitoring for protection of the public in normal situations and after accidents for potential long-term exposures. The principles or basic requirements relevant to radiation protection are given in the IAEA Basic Safety Standards.

107. Exposure classifications are divided into normal and emergency situations. Normal situations are covered by this Guide. Emergency monitoring is also important and should be provided for any major installation as determined by the Regulatory Authority. That subject, however, is outside the scope of the present Guide. Some aspects of monitoring during emergency situations are described in the IAEA Safety Series No. 86 and 94 for nuclear facilities, No. 91 for medical applications, and No. 87 for transport of radioactive materials [6-9].

108. Further classification of the normal situation can be divided into public exposure and occupational exposure. This Guide describes public exposure. Occupational exposure is outside the scope of this Guide and is discussed in the IAEA Safety Series No. 84, 95 and 50-SG-D8 [10-12].

109. Sources may be defined as physical entities within particular practices (e.g. the release of radioactive effluents from nuclear or industrial installations) that are controllable or as circumstances leading to exposure to the public that may not be controllable (e.g. exposures from natural radiation). Radiation sources which require or may require monitoring are classified into nuclear facilities, non-nuclear facilities utilizing ionizing radiation, natural sources, fallout from weapons testing, radiation-emitting consumer products, medical applications and transportation of radioactive materials. This Guide deals with these sources with the exception of: (1) medical uses of radioactive material or radiation sources in diagnostic or therapy procedures; (2) transportation of radioactive materials and (3) radioactive material disposed of as waste. Because the contribution to the dose to the public from both individual patient discharges (excreta) who have been treated with radioisotopes for medical purposes and transportation of radioactive materials are negligibly small in most situations, they are not covered in this Guide. Monitoring related to

occupational exposure from transport of radioative materials is found in the IAEA Safety Series No. 6 [5]. Additionally, the topic of radioactive waste disposal is covered in

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110. Monitoring itself can be divided into source monitoring, environmental monitoring and individualmonitoring (see Figure 1). Source monitoring involves measurements of a defined source of radiation and discharges and refers to measurements of dose rates or activity concentrations ineffluents resulting from a defined source or practice. Environmental monitoring can also be divided into three types: single-source, multiple-source, and widespread source environmental monitoring. The first two types of monitoring are concerned with measurements in the environment and environmental samples taking into account exposure pathways to the public, whereas widespread monitoring involves environmental monitoring by the regulatory authority of both natural and artificial types of radiation (see Section 4.5 for additional information).

111. Regulatory authorities under special circumstances may wish to carry out multiple source environmental monitoring to assess the dose to the public from all sources (whether controllable or not) so that the contributions of different types of sources are established and trends noted.

112. In exceptionally rare circumstances, Regulatory authorities may perform individual monitoring where the assessed dose to the critical group approaches the dose limit. This situation is likely to be highly unusual.

# FIGURE 1

## SIMPLIFIED MONITORING DIAGRAM

113. Interpretation of the results of monitoring procedures is taken to be an integral part of monitoring itself. Interpretation relies on the use of models to some extent irrespective of whether the monitoring is of the source, the environment or the individual. When monitoring is confined to the source, extensive use of models is required to apply the information from monitoring to the assessment of dose to members of the public. When environmentally dispersed radionuclides are ingested or inhaled, models are required to cover environmental transfer processes as well as the biokinetics of the radionuclides in the human body and the associated dosimetry. Even in the case of individual monitoring, dosimetric models are required to relate the quantities of radionuclides in the body to dose. This Guide therefore includes a description of the principles of modelling and a discussion of the relationship between modelling and monitoring.

114. This Guide deals with the same subjects as the ICRP Publication 43 [17]. Both of these reports cover monitoring for radiation protection of the public. In this Guide relevant recommendations, derived limits, authorized limits, reference levels, etc. are not discussed and modelling is only briefly mentioned. The emphasis in this Guide is on the implementation of the requirements of the BSS. The contents of the text are, however, consistent with ICRP Publication 43 [17].

115. The terms used in this document have the meanings assigned to them in the Basic Safety Standards [4].

## 1.4 STRUCTURE

116. Sections 2 and 3 of the main text of the Guide outline the role of Regulatory Authorities for radiation protection of the public and the objectives of monitoring programmes, respectively. In Section 4 the design of monitoring programmes is given for source (including effluent) monitoring, single-source environmental monitoring, multiple-source environmental monitoring, widespread environmental monitoring and individual

monitoring. Sections 5 and 6 discuss modelling and requirements for recording and reporting. The final Section 7 delineates quality assurance in the monitoring programme.

# 2. BASIC REQUIREMENTS FOR RADIATION PROTECTION OF THE PUBLIC

## 2.1 RESPONSIBILITY FOR MONITORING

201. The responsibilities for source and environmental monitoring will vary according to regulatory requirements. All sources, unless they are formally exempted or excluded by the Regulatory Authority should be subjected to the provisions of this Guide. It is the responsibility of the Regulatory Authority to specify such sources that may be exempted or excluded from the requirements of environmental and sources monitoring. In cases where a source or practice is exempted or excluded, no environmental monitoring would be required. Additional guidance regarding the principles for the exemption of radiation sources and practices from regulatory control can be found in Safety Series 89. [ ]

202. Regulatory authorities *shall* impose requirements on the conditions of operation of major controllable sources, ensuring that control of the discharges is optimized in accordance with the principal requirements of the BSS. They should be satisfied, through registrant or licensee source and environmental monitoring programmes, that the dose limits/constraints for members of the public are being adhered to.

203. Regulatory authorities should take into account the nature of the source and specify source discharge limits for effluents resulting from the operation of such sources and practices (see Safety Series 77 for additional modeling regarding discharges). They shall impose requirements on registrants and licensees to ensure that *monitoring and measurements shall be conducted with the parameters necessary for verification of compliance with the requirements of the BSS [p.27]*. The responsibility for source monitoring should usually be given to the management responsible for the source (i.e., the registrant or licensee), but regulatory authorities themselves should approve these procedures and may conduct independent verifications of their own.

204. Regulatory authorities should require the management of major controllable sources to undertake both a defined source and environmental monitoring programme outside the site containing the source. These programmes are generally designed to assess the level of exposure of the critical group from that source. For this purpose, the measurements carried out in the programme should be complemented by the use of specified environmental, biokinetic and dosimetric models.

205. Regulatory authorities should also specify requirements on the conditions of operation of intermediate and minor sources. The requirements should be based on the level of exposure resulting from each source and on the total number of such sources. These requirements should include an authorized limit and monitoring procedures. For minor sources, however, regulatory authorities should normally require only a demonstration that a source is being controlled within the dose constraints. Regulatory authorities should not require routine environmental monitoring programmes for minor sources. For the assessment of dose from intermediate sources they may require simple programmes and the use of specified models. Only occasional verification of the registrant or licensee environmental data is suggested. (see Section 4, Figure 2 for additional information).

206. In exercising these responsibilities the regulatory authorities should:

(a) ensure that the public and the environment are protected by establishing and implementing appropriate regulations to enure that the dose limits are not exceeded and, if necessary, develop their own independent monitoring programmes;

(b) identify all sources in the environment that may significantly contribute to exposure of the public; and conversely, identify all sources that may be exempted or excluded from the requirements for environmental monitoring;

(c) ensure that the registrant or licensee complies with the appropriate regulations and regulatory requirements for compliance with the dose constraints and limits

including the establishment and implementation of such environmental monitoring programmes as are necessary;

(d) demonstrate that judgements regarding the safety of the public are based upon valid scientific information to satisfy public concerns, if any exist, and that there are no unauthorized sources of exposure;

(e) assess the total effect of sources that may not individually require monitoring; and where necessary, undertake multiple source environmental monitoring in circumstances where there may be several sources irradiating the same group of people; and

(f) ensure that provisions are made for quality control of the registrants, licensees and their own programmes.

207. Registrants and licensees should prevent any unacceptable radiation or contamination hazard to the public resulting from operations within the installation, discharges to the environment or from materials distributed to members of the public and ensure that radiation protection is optimized. Adequate source and environmental monitoring programmes which are approved by the Regulatory Authority should be implemented for all sources which may cause radiation exposure to members of the public. Recent revisions to Safety Series 77 provides guidance on a structured approach for establishing discharge limits from sources that could cause exposure to members of the public.

208. Registrants and licensees should *monitor and verify compliance with the BSS using suitable equipment involving verification procedures. This equipment shall be properly maintained and tested and shall be calibrated at appropriate intervals with reference to standards traceable to national and international standards [BSS p. 27].*

In exercising these responsibilities, registrants and licensees should:

(a) perform all necessary pre-operational investigations (including, if necessary, pre-operational monitoring) to serve as a basis for effective monitoring programmes;

(b) design and provide means for performing adequate source and environmental monitoring programmes during and after operation that will demonstrate that doses to the public satisfy the regulatory requirements and are as low as reasonably achievable.

## 2.2 IDENTIFICATION OF SOURCES

209. The public may be exposed to a variety of radiation sources through a number of different pathways. These sources are classified into natural and artificial. Natural sources consist of cosmic rays, cosmogenic radionuclides, and terrestrial radiation sources, such as naturally-occurring $^{40}K$, $^{238}U$ and $^{232}Th$ and their decay products. Medical exposure, fallout from weapons testing, and radiation from nuclear fuel cycle activities belong to artificial sources. Some of the natural sources as well as most of the artificial sources are controllable and the attributable dose may be reduced. It is necessary to know the level of each exposure from each of the sources and identify their degree of controllability.

## 2.3 CONTROL OF EXPOSURE

210. The exposure of individuals can be limited either by the control of a practice or by intervention. Most of this Guide is concerned with monitoring programmes for practices. However, some guidance is given on monitoring programmes for situations, such as radon in homes, that may require intervention. In public exposure for practices, the controls should be applied at the source. Only if these cannot be made effective should controls be applied to the environment or to individuals.

211. For any practice, the scale and extent of the environmental monitoring effort should be commensurate with the significance of the expected doses to individuals, and collective doses to populations, under both normal and accident conditions. Many practices may require no monitoring programme of any kind, some may require routine source monitoring but only occasional checks on environmental levels (with or without provision for emergency monitoring) and some may require continuous and comprehensive monitoring of both source and environment, with emergency monitoring capability.

212. There are several types of practice for which monitoring programmes are required on the grounds both of routine effluent releases and the potential for higher releases. Installations of this type are regarded as *major* from the point of view of monitoring requirements and will always be subject to source as well as environmental monitoring; this will usually be continuous to act as a check on routine releases and to provide a warning of deviations from normal. The term *source monitoring* usually requires source as well as effluent monitoring programmes which should provide a systema' assessment of major pathways of exposure and be sufficiently comprehensive to detect the introduction of new pathways. The routine monitoring programme also forms the basis for the emergency monitoring programme. Most installations within the nuclear fuel cycle may fall into this *major* category. Regulatory aut':orities may wish to make provisions for types of sources that are intermediate between major and minor categories.

213. It is clear that there are many practices from which the external dose-rates in places accessible to the public are very low, the normal releases of radionuclides in effluents are very low and the potential for an accidental release is very low or non-existent. Individual practices of this kind can be regarded as *minor* from the point of view of environmental monitoring requirements. Sources which themselves are minor may be distributed in large numbers to the public. The most effective way of control in such cases is by source monitoring before distribution. Consumer products are such an example [19].

214. Once the exposures from all sources are obtained, the contributions from the controllable sources should be estimated to clarify their relative significance.

# 3. OBJECTIVES OF MONITORING

## 3.1 GENERAL OBJECTIVES

301. The primary objectives of monitoring for radiation protection of the public are:

(a) to ensure that the exposures to members of the public or to *critical groups* are below the regulatory authority's established dose limits and constraints;

(b) to assess the effectiveness of source controls and to enable the prompt detection of any significant increase in environmental radiation levels or "off-site" contamination that could be attributable to the radiation or radioactive discharges emitted by the source(s); and

(c) to establish and maintain wherever appropriate, the capability to carry out emergency monitoring in case of unexpected releases of radiation or radioactive materials to the environment causing contamination due to accidents or other unusual events.

302. Possible supplementary objectives include:

(a) the identification of new exposure pathways or changes in the relative importance of known pathways;

(b) the validation or improvement of relevant environmental transfer models;

(c) the estimation of variability of monitoring results including the fluctuation of natural radiation;

(d) the estimation of collective doses;

(e) the provision of information to the public additional to that resulting from the primary objectives.

The basic scheme for radiation monitoring for protection of the public is illustrated in Fig. 2.

## 3.2 SOURCE MONITORING

303. Monitoring for radiation protection of the public can be divided into several categories: source monitoring (which includes source and effluent monitoring); environmental monitoring (which includes single-source, multiple-source and widespread sources environmental monitoring) and in extremely rare cases, individual monitoring for members of the public.

304. The objectives of source monitoring are:

(a) to demonstrate compliance with the authorized and/or operational limits on releases of airborne and liquid radioactive materials;

(b) to provide adequate data and information for the estimation of public exposure that results from the operation of the installation;

(c) to indicate whether and to what extent environmental monitoring may be required;

(d) to provide adequate information to demonstrate that the plant operation and effluent treatment and control system are performing properly;

(e) to assure the public that the operation and releases are being properly controlled;

(f) to provide early warning of any departures from normal; and

(g) to detect and identify rapidly the nature and extent of any unplanned circumstances that may lead to exposure of the public.

## 3.3 ENVIRONMENTAL MONITORING

305. The primary objectives of environmental monitoring are to:

(a) assess actual or potential doses to individual members of the public or members of the *critical group* from operation of each source;

(b) evaluate the adequacy and effectiveness of the containment, and control systems; and

(c) detect changes and evaluate long-term trends in activity concentrations or dose rates in the environment.

306. The environmental monitoring programme may fulfill one or more of the following additional supplementary objectives:

(a) confirm predictions based upon source monitoring and models of transfer through the environment;

(b) provide reassurance that doses based on source monitoring are not seriously in error due to unmonitored releases;

(c) discover any new pathways or modes of exposure;

(d) maintain capabilities for rapid evaluation and response to an unusual situation;

(e) provide information to the public wherever necessary on activity concentrations in the environment or on *collective dose* or *public exposure*; and

### 3.3.1 Single-source environmental monitoring

307. When environmental monitoring is carried out to assess the impact of a particular source, it is referred to as *single-source environmental monitoring*. The objectives of this monitoring programme may vary with the stage of operation. In the pre-operational stage, single-source monitoring is not applicable and environmental monitoring is designed to establish existing levels of radionuclides and dose rates in the environment, to test the methodology of environmental monitoring, to elucidate local factors (meteorology, hydrology, population distribution, land use etc.) that will affect doses and to establish monitoring points and the type of environmental samples. In the early stages of operation, quite frequent and detailed measurements may be required to confirm predictions of the behavior of the source and movement of radionuclides in the environment. As experience is gained, it may be possible to reduce the scale of both source and environmental monitoring. Since many operations do not lead to readily detectable levels of radionuclides in the environment, it may not be possible to detect environmental levels in the early stages of operation, but some measurements should be carried out as a check. An established monitoring programme must be reviewed at regular intervals to ensure its continuing validity. In the decommissioning phase, quite different monitoring programmes may be required.

### 3.3.2 Multiple-source environmental monitoring

308. Multiple-source environmental monitoring may be carried out in rare circumstances by the Regulatory Authority where there may be several sources potentially exposing the same group of individuals. An example of this type of monitoring may occur when there are several licensees and/or registrants within close proximity to one another that have been granted the authority to discharge to the same body of water. In this case, the regulatory authority may want to perform environmental monitoring of a particular critical group specific to this area (i.e., fishermen). For further information regarding this type of environmental monitoring program, see Section 4 of this Guide.

### 3.3.3 Widespread environmental monitoring

309. Monitoring programmes may be carried out to assess doses from natural radionuclides, fallout from weapons nuclear testing, or even from consumer products containing radioactive material in order to assess the regional and global components of exposures resulting from releases of long-lived radionuclides from the nuclear fuel cycle that are widespread in the environment.

310. Widespread environmental monitoring programmes may be carried out by the Regulatory Authorities to fulfill one or more of the following objectives:

(a) provide an assessment of the *collective dose* to the whole population from these sources;

(b) assess levels, detect changes and evaluate long-term trends in the total dose and the relative contributions of each source to the total;

(c) assess the need for control of any specific source of exposure (e.g. *intervention* to reduce radon concentration in homes);

(d) provide information to the public on environmental levels and doses; and

(e) maintain capabilities for rapid evaluation and response to unusual situations.

## 3.4 INDIVIDUAL MONITORING

311. In exceptionally rare circumstances, if the assessed dose to the critical group based on environmental monitoring is close to the dose limit monitoring of individual members of the public may be carried out.

# 4. DESIGN OF MONITORING PROGRAMMES

## 4.1. RELATIONSHIP BETWEEN SOURCE AND ENVIRONMENTAL MONITORING

401. Different types of monitoring programmes may be required according to whether the source emits radiation, whether radionuclides are discharged from a defined location or whether the source is widespread in the environment. The first category includes installations in the nuclear fuel cycle such as uranium mines, mills, enrichment and fuel fabrication plants, nuclear power reactors, spent fuel reprocessing plants, waste storage and disposal sites. It also includes research reactors, research institutes, hospitals and medical research institutes, isotope production and handling facilities and their associated waste management operations. The release to the environment of naturally-occurring radionuclides from the non-nuclear industry could also be included in this category. In the second category, widespread sources include those distributed to the public (consumer products, natural gas and building materials or manufactured goods that may contain higher than average concentrations of radionuclides) as well as natural radiation, fallout from nuclear weapon testing and contamination due to past accidents. Sources which are distributed to the public represent practices and for these, control may be exercised before distribution. For these latter sources, the same considerations apply in the design of monitoring programmes but the extent of the actual monitoring will be generally much smaller.

402. The scale of the monitoring programme should reflect the significance of the dose to critical groups and to the population from planned releases. For major installations, the routine environmental monitoring programme should be designed to provide a good basis for post-accident monitoring. In the event of an accident, this monitoring programme will need to be modified and expanded. Guidance for monitoring in accident situations are given in the IAEA Safety Series No. 86 and 94 [10, 11].

403. Major sources in this first category will require continuous source monitoring and comprehensive environmental monitoring. Intermediate sources may require source

monitoring with only occasional checks on environmental levels that are carried out to confirm predictions based upon actual registrant or licensee source monitoring. Minor sources will usually require no monitoring at all, control being adequately exercised by administrative checks on source inventory. In the case of natural radiation, fallout from weapon testing and widespread contamination due to past incidents, the measurements are carried out by the Regulatory Authority in the environment for the assessment of dose to members of the public. Multiple-source environmental monitoring may be required to assess the dose to critical group from several sources at the same site.

404. An installation may require a source monitoring programme or both source and environmental monitoring to assess the impact of its operations. Source monitoring provides information on dose rates and quantities of radionuclides released to the environment as a result of operations at each installation. These data, in combination with other relevant information and models, may be used to assess doses to the critical group and to the population as a whole. Environmental monitoring refers to the direct measurement of dose rates in the environment and of activity concentrations in environmental media. In general, there may be more confidence in dose assessments on measurements made close to individuals because uncertainties inherent in the models used to assess environmental transfer are reduced. However, the effect of the source on dose rates and activity concentrations in the environment is rarely detectable during normal operations and dose assessments are usually based on source monitoring. In rare circumstances where the effect of the source on dose rates and activity concentrations in the environment is readily detectable, dose assessments may be based on environmental monitoring.

405. The planned monitoring programme should be appropriate for the type of installation and environment, the expected doses and their proximity to the dose limits or dose constraints. Moreover, it should enable the detection of any significant unplanned releases. Monitoring must be adequate to fulfill the objectives, but unnecessary measurements are to be avoided.

406. In general, detailed design and operation of source monitoring and environmental monitoring programmes are treated separately since the dose rates and quantities of radionuclides involved are very different. In may cases, different agencies, as well as individuals are often involved. However, when both types of programme are conducted, there must be good liaison between the two because information obtained from one programme may influence the conduct of the other. Generally, all programmes should be subject to periodic review to ensure that measurements are relevant for the purpose of the programme and that no significant routes of discharge or of environmental transfer have been overlooked.

## 4.2 SOURCE MONITORING

### Design of source monitoring programmes

407. Design of the source monitoring programme should be such that it enables verification of compliance with the discharge limits and criteria as specified in the authorization issued by the Regulatory Authority. This may require radionuclide- specific measurements or gross activity measurements as appropriate. Measurements should be carried out at the point where data best represents the material actually released; this will normally be at the point of release.

408. For both airborne and liquid effluents three types of measurements are possible:

a) intermittent sampling and laboratory measurements of radio activity concentrations in the sample;

b) continuous sampling and laboratory measurements of radioactivity in the sample; and/or

c) on-line monitoring of discharged effluents.

The choice of the sampling and measurement procedure will depend on:

a) the expected variation in time, if any, in the release rate of the radio-nuclide;

b) the possibility of unplanned releases requiring prompt detection and notification; and

c) the type of activity to be measured.

409. In all situations, it will be necessary to have provisions for the accurate determination of the volume of effluent discharged so that the total activity discharged over a given time period can be computed based on measurement of activity concentration.

410. If the release rate is reasonably steady intermittent sampling is adequate. If the release rate can vary, continuous sampling that is representative of the effluent over the discharge duration will be required. Continuous on-line monitoring is required if rapid fluctuations are expected to occur. in the concentrations and if the possibility of unplanned releases exist.

411. Other information that could be included in the monitoring programme are:

a) chemical form of the radio-nuclide released;

b) solubility of the radio-nuclide species;

c) particle size distribution in the case of airborne effluents;

d) pH in the case of liquid effluents; and

e) meteorological and hydrological factors.

Special considerations for facilities releasing naturally-occurring radionuclides

412. Although the general objectives and design of source-related environmental monitoring programmes also apply to facilities that releases naturally occurring radionuclides, there are some special difficulties that merit particular attention. Such facilities include uranium and thorium mines and mills, and phosphate fertilizer plants. A major difficulty of the environmental monitoring programme is to assess the effect of releases in the presence of natural levels of the same radionuclides.

413. Mining sites are situated in areas of high natural concentrations of these radionuclides and milling facilities are frequently situated nearby. In these areas, the normal concentrations of naturally-occurring radionuclides in environmental media are high and subject to considerable variation. In such situations, assessments of doses to the public resulting from these operations is primarily based on source monitoring and modelling. However, where environmental monitoring is undertaken, registrants or licensees will wish to distinguish the effect of the releases from normal levels. An adequate pre-operational programme is then essential to assess normal levels and their variation. The operational

programme will then provide results which can be compared with pre-existing levels (absolute values and isotopic ratios) to demonstrate whether or not releases are detectable.

Monitoring Techniques

414. Monitoring of released radionuclides may be based on two techniques:

(a) The use of detectors either immersed in the airborne or liquid effluent stream or outside of but close to the release duct. In these situations, monitoring provides direct measurements of the effluent radioactivity. Contamination of detectors may, however, introduce some difficulties;

(b) Sampling of airborne or liquid effluents and measuring the radioactivity of this sample.

415. These monitoring techniques permit alternative modes of operation. In the first, the measuring equipment gives a direct response to the registrant or licensee of the facility and may be connected to warning devices in order to enable them to take corrective actions if necessary. The second mode involves in-situ or laboratory evaluation after sampling. Both measurement techniques may be used in certain situations to supplement each other.

416. 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.

417. The sampling procedures should take account of the following requirements:

(a) The sampling point should be chosen to provide a representative sample;

(b) Sample collection should be designed to obtain samples which may provide quantitative estimation of the radionuclide releases from the source.

418. 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 and the nature of the materials to be measured, etc. Sampling can be continuous, periodic, special or self-actuated. Continuous sampling is required when there may be wide variation in the concentration of the radionuclides or in the discharge-rate, or when the likelihood and potential consequences of unplanned releases are not trivial. Periodic sampling may be sufficient when the concentrations of all radionuclides are relatively constant, when unusual variations are unlikely and when the predicted doses are low. Periodic sampling may be actuated automatically. The frequency of such sampling should be periodically reconsidered. Special sampling is carried out, whenever necessary, to monitor either special releases required by operational conditions or unusual occurrences. Self-actuated sampling is accomplished by devices which automatically collect samples when rapid variation occurs in the concentration of the radionuclides released. Actuation of such sampling may be automatically linked to devices which provide a direct measurement of the quantities released.

419. Laboratory analyses may be required to supplement in-situ measurement; for some nuclide, they may be the only means of measurement. Gamma-ray emitting radionuclides may be determined by direct measurement with detectors of adequate resolution; natural uranium and thorium may be determined by chemical methods; some radionuclides can be determined only by radiochemical separation followed by appropriate radiometric techniques [21,22]. The measurement procedures must provide sufficient reliability, accuracy and comparability of the results.

## 4.3 ENVIRONMENTAL MONITORING

420. An environmental monitoring programme is required only when the expected dose rates or releases of radionuclides may result in a critical group or the population as a whole receiving a significant fraction of the dose constraints specified by regulatory authorities. However, there may be circumstances in which some environmental monitoring may be carried out to provide information to the public. When an environmental monitoring programme is carried out, the effort devoted to it should reflect the significance of the doses and their proximity to appropriate limits. Many practices will not require environmental monitoring. In these situations, the source monitoring programme should provide sufficient information to estimate doses and environmental concentrations. Where routine environmental monitoring is not required for radiological protection purposes, registrants or licensees may wish to undertake a limited programme of environmental measurements to provide confirmation of estimates based on source terms and modelling.

421. A source may give rise to exposure of members of the public through multiple routes. A requirement of the early stages of planning a monitoring programme must be to consider the various potential routes of exposure, their magnitude and likely variability. A fixed point source that gives rise to external dose rates only may be a quite simple situation to assess. At the other extreme, an installation that discharges a range of radionuclides into a complex environment that is used for habitation, industry, recreation or food production may require a detailed analysis to indicate which are the predominant pathways of exposure. At the planning stage, it is necessary to use information on source characteristics, releases of radionuclides, environmental pathways and modelling studies to assess the impact of the source and indicate important pathways. Another IAEA publication [23] gives recommendations on these assessments.

422. An important concept in this respect is that of the critical group. This is a relatively homogeneous group of members of the public who, because of their age, diet or habits, are expected to receive the highest dose. The dose constraint applies to the mean dose to this group. ICRP has provided some guidance to assist in the determination of critical groups [17] and that guidance is commended to regulatory authorities. The

requirement for homogeneity has certain implications for the size of the group. Usually, the group will not consist of a single individual. However, in extreme situations, for example, when considering exposures that may occur far in the future, it may be convenient to define the critical group in terms of a single hypothetical individual. In practice, the critical group size could be relatively small, although in a situation where a population is exposed uniformly, it would be possible to consider the entire population as the critical group. Those aspects of behaviour that are most likely to affect the doses received include proximity to the source, the occupancy time in areas of elevated external dose rates or activity concentrations in air, and the consumption rates of foodstuffs.

423. To select the group that is most highly exposed it is necessary to characterize the distribution of habits in the relevant population. The detail required will depend upon the estimated dose. If this is low, national statistics may be used or reasonably conservative estimates may be based on national statistics. There are some circumstances, however, where there are substantial variations in characteristics and where doses may be such that more detailed analysis is warranted. Surveys provide a sample of the distribution of characteristics at a particular time and it should be recognized that the results of any one particular survey may be subject to fluctuations. The survey data should be used to postulate the underlying distribution and subsequent surveys should be examined to confirm or modify it. Once the underlying distribution is established it is then necessary to select the critical group. To satisfy the homogeneity criterion, it is suggested that the ratio between maximum and minimum estimated doses within a critical group should not exceed an order of magnitude unless the mean dose approaches the authorized limit; in that case, the range should not exceed a factor of three. Recognition must also be given to the fact that individuals may be members of more than one critical group.

424. In dose calculations, account should be taken of the age and appropriate biokinetic parameters of the critical group and of the different chemical and physical forms of radioactive material in the environment.

Pre-operational studies

425. Pre-operational studies are necessary to provide data for estimation of doses to critical groups and collective doses to populations from planned operations, for the establishment of limits and conditions of releases to the environment and for the design of the monitoring programme. The following points may need consideration:

(a) the types and activities of radionuclides that will be released, their physical and chemical forms, the method and route of release and the rates of release;

(b) the transfer of radionuclides through the environment, including consideration of dispersion and reconcentration mechanisms and seasonal variation;

(c) natural and artificial features of the environment that affect this transfer, e.g., geological, hydrological, meteorological conditions, vegetation, presence of reservoirs or harbours;

(d) the utilization of the environment for agriculture, water and food supplies, industry, habitation, recreation.

(e) the distribution of the population according to age, sex, and dietary, occupational, domestic and recreational habits;

(f) the existing levels of radionuclides in the environment and their variability;

(g) the identification of concentration mechanisms;

(h) the existence of any chemical pollutants that may affect the transfer of radionuclides;

(i) the identification of critical nuclide and critical exposure pathways;

(j) the preliminary determination of critical groups;

(k) the prediction of doses to population groups and collective doses to the population as a whole.

425. The pre-operational studies should indicate which radionuclides and pathways of exposure are of prime importance, both in relation to critical groups and the population. These studies may enable derived limits for concentrations in environmental materials to be calculated; derived limits correspond to the dose limits and the regulatory authority may wish to specify investigation levels, set at some fraction of derived limits, above which some specified action or investigation should take place. The pre-operational programme might also identify suitable indicator materials; these are media that do not necessarily form part of the pathway to man and are therefore not used for dose assessments, but are sensitive indicators of trends in environmental levels. The pre-operational programme may also serve to train staff and to test the equipment, instruments and organization of the operational programme.

Monitoring Techniques

426. A sampling strategy that includes specification of the type of samples to be taken, sampling locations, frequency sampling, etc. should be adopted by Registrants or licensees that enables the dose to the critical group among the members of the public to be assessed with sufficient accuracy. These samples could come from the atmosphere, aquatic, and terrestrial compartments in the environment. They are chiefly air, water, and foodstuffs. External radiation exposure from effluent plumes and submersion doses as well as external exposure arising from ground or sediment-deposited activity should also be assessed. Measurement techniques include gross activity estimates, radionuclide-specific spectrometry

with or without special radiochemical procedures. The techniques adopted would also depend on the physical and chemical nature of the contaminant: particulates , inert gases, etc.

427. The monitoring programme could also include samples that act as sensitive indicators or indicators of long-term accumulation of radioactivity in the environment that provide historical information on radioactive discharges. The latter samples include soil, sediment, seaweeds, animal thyroids, etc., depending on the specific radionuclide of interest.

428. These registrant or licensee environmental monitoring programs should be kept under constant review to enable the detection of any new pathways of exposure and to assess the need for modifications, if any.

### 4.3.1. Single-source environmental monitoring programmes

429. The scale of a single-source environmental monitoring programme will be determined primarily by the significance of the expected doses to the critical group and measurements will be concentrated on important pathways. An additional consideration will be the need for rapid information on environmental levels and activity concentrations that may be required in unusual circumstances. Simplified pathways of exposure to man from radioactive materials released into the atmosphere and water bodies are illustrated in Fig. 3. However, other factors should also be considered:

(a) the extent to which the operation and discharges are routine and unchanging;

(b) the need to evaluate the adequacy and effectiveness of the containment and control system;

(c) the need to detect changes and evaluate long-term trends in activity concentrations or dose rates in the environment;

(d) the significance of any changes in the physio-chemical form of radionuclides;

(e) frequency of sampling or measurement which may depend on the half life of the radionuclide.

430. Single-source environmental monitoring programmes should be reviewed periodically. There may be changes in the environment itself or changes in the registrant's or licensee's discharge to the environment; in particular individuals' occupational, recreational and dietary habits may change. Changes in the habits of critical groups will be revealed by periodic habit surveys but those in charge of environmental monitoring programmes should be alert to changes in sub-critical pathways as well. Changes in the manner of operation of the installation or in the nature of the discharges should also lead to reassessment of the environmental monitoring programme to ensure its continuing validity. An example for the design of an environemtnal monitoring programme for a major source is provided in Fig. 4. Results from the monitoring programme should be critically reviewed to assess the need for any modification to the programme itself. With experience it should be possible to reduce the scale of the environmental monitoring programme or to stop it completely, but there may be situations that indicate a need for more or different analyses. One problem that the programme designer must contend with is the increasing public demand for reassurance on the topic of environmental contamination with radionuclides. Even if it is possible to demonstrate scientifically on the basis of source monitoring and modelling that an environmental sampling programme is not required, there may still be public pressure to confirm by a limited programme of environmental measurements that the effect of discharges is small as a matter of public reassurance.

431. For sources that require comprehensive environmental monitoring programmes it is necessary to consider a number of routes of exposure [see Figure 3]. Discharges to the atmosphere may give rise to external doses from the plume or from deposited radionuclides, the radionuclides may be inhaled or they may be transferred through food chains. Integrating dosimeters at suitable locations can adequately assess external dose rates. Doses from

inhalation may be assessed by continuous collection and periodic measurement of airborne radionuclides. Passive collectors can be used as indicators of trends in airborne concentrations. In all these situations, placement of the sampler is important and depends upon the objective: whether it is to measure maximum levels or levels at sites of population. All environmental dispersion and concentration mechanisms must be taken into account. For example, radionuclides in air may not originate just from stack discharges, but may also be due to resuspension from marine or terrestrial sources. Foodstuffs such as milk may be collected frequently; others will be sampled at the appropriate time according to seasonal production. Occasional measurements of integrating media such as soil and some bio-indicators may be useful to demonstrate whether there is long-term accumulation in the environment. Foods, such as a game, fruits and honey, should not be overlooked .

432. For release to fresh and coastal waters, the routes of exposure are generally through drinking water, irrigated foodstuffs, fish and other edible aquatic organisms and through contamination of beaches and soils. In areas where solar evaporated salt is consumed directly, this may be monitored.

433. In situations where cooling water or waste ponds are located at an installation, nearby ground-water wells and surface water may be monitored for possible seepage from the ponds. Where radioactive wastes are buried, monitoring may be carried out to detect contamination of ground or surface waters.

434. In many situations, however, radionuclides may not be readily detectable in pathways of radiological importance. Therefore, doses must be estimated from source monitoring data and models. In this case indicator materials may provide a sensitive means of monitoring trends in the environment. Food chains and other environmental pathways should be examined for organisms or materials that provide a sensitive and reliable indicator of changes in environmental levels. For example, mosses and lichens can be used to provide information on the deposition of airborne radionuclides and seaweed and algae can be used to assess changes in the marine and fresh-water environments, respectively.

### 4.3.2 Multiple-source environmental monitoring

435. Regulatory authorities may wish to keep under review the level of radionuclides in the environment that may result from a combination of sources, although each does not necessarily require an environmental monitoring programme. Such a situation could occur for example if several hospitals or research institutes may discharge radionuclides into the same body of water; the regulatory authorities may then wish to monitor water supplies to assess the aggregate effect of all the discharges. However, for proper design of the monitoring programme, the regulatory authorities would need some information on the radionuclides discharged, their chemical and physical form and the frequency with which discharges are made, so that appropriate collection and measurement techniques could be employed.

### 4.3.3 Widespread environmental monitoring

436. Widespread sources of natural or artificial radioactivity may lead to radiation exposure to members of the public. These types of sources include consumer products or other products distributed to the public, fallout from weapons testing and the regional and global dispersion of long-lived radionuclides released from the nuclear fuel cycle, as well as natural radiation. Since the sources are widespread, it is not possible generally to define critical groups, in the sense used in Section 2. Hence, source and environmental monitoring programmes may need to be developed and implemented by the Regulatory Authority to evaluate changes in the background levels of radiation or radionuclides as a result of regulatory-approved activities.

437. Doses to members of the public from background radiation may come from naturally-occurring radiation from cosmic rays, terrestrial radiation (radon, uranium and thoron), as well as through intakes of radionuclides in diet (i.e., drinking water and food). In addition, naturally-occurring radionuclides (such as the use of phosphate fertilizers or the

burning of coal or gas) released by a process or as a byproduct from the non-nuclear industry can also contribute to the dose to members of the public.

438. If the Regulatory Authority's choice is to implement a widespread monitoring programme, it should have a wide geographical scope to ensure an adequate estimate of the collective dose to the population; for some sources, especially radon, it is necessary to consider local variations. Such monitoring programmes have the objective of keeping all sources of exposure under review at the national level. In addition, the Regulatory Authority may, however, implement additional source monitoring for items such as consumer products that may contain enhanced concentrations of natural radionuclides such as naturally-occurring uranium found in building materials, jewelry, dishes, natural gas or mineral water, if there is a public inquiry or interest in having this informational available. In some cases, the radionuclide content of materials used in building construction may influence the dose to the inhabitants by both external exposure or by inhalation of airborne activity. Control, if required, must be exercised by the Regulatory Authority before distribution to the public and this may require a continuing programme of monitoring and approval.

439. The Regulatory Authority should determine if the following may need evaluation: external radiation; radionuclide concentrations in air; soil; wet and dry deposition; water; plants and animal products (aquatic and terrestrial). The sampling and measurement techniques are in principle the same as those described above. The important additional consideration is the need to make measurements or collect samples on a national basis so as to provide an assessment of collective dose.

440. The regional and global components of collective dose from long-lived radionuclides discharged from nuclear facilities to the environment are best estimated from source terms and modelling. Although these radionuclides can be measured in the environment, the contribution of the nuclear fuel cycle must be evaluated against a background level due either to natural production or fallout from weapons testing. Environmental measurements of tritium, carbon-14, krypton-85, iodine-129, and caesium-

137 are examples. Doses to members of the public from these sources typically result from external irradiation and from internal irradiation through the consumption of foods.

441. The resulting Regulatory Authority environmental programme is generally characterized by wide geographical coverage. The main factors that influence the location of the measuring and sampling points are:

(a) the size of the territory considered;

(b) geology, hydrology and other principal geographical features (mountains, coasts, rivers, lakes);

(c) climate (precipitation);

(d) population distribution; and

(e) dietary and living habits.

442. For example, the siting of measuring and sampling points depends upon the likely variability of dose rates and activity concentrations with location and on the population distribution. In the case of diet, collection of representative samples of foodstuffs and water should take account of geographical and seasonal factors to ensure that all important sources are included.

443. For consumer products, Regulatory Authorities may wish to control the distribution. Considerations such as the justification for using a radioactive source or a device that may give rise to doses to the public are beyond the scope of this report, although regulatory authorities will wish to consider the relative merits of such devices and any non-radioactive alternatives. Additional guidance may be found in Refs. [29, 30].

444. Once the product is in the possession of the consumer, there is usually no further control of its handling, maintenance and disposal. The radiological assessment must, therefore consider the doses that can arise during manufacture, distribution, use, credible misuse and disposal. The regulatory authorities may wish to arrange for the testing of a number of devices of each type, to calculate the doses that may arise under the various circumstances given above and to decide whether the product is acceptable. If acceptable, approval may be given for distribution and further testing may be necessary only when modifications are made to the design. If the doses are not justified, the product may not be distributed; the manufacturer may modify the design so as to reduce doses to justifiable levels and resubmit the product for testing. Where national and international standards exist, any product distributed to the public must comply with these standards. Some examples of suitable testing and appraisal programmes are given below. More comprehensive information is available in Refs. [19,28-30].

## 4.4 INDIVIDUAL MONITORING

445. Regulatory authorities may require individual monitoring amongst members of the public (bioassay, whole body counting, personnel monitoring for external exposure) if the assessed dose from environmental monitoring data is close to the dose limit. Regulatory authorities may wish to ensure that adequate faciliites exist for this purpose.

# 5. DOSE ASSESSMENT

## 5.1 MODELLING

501. The use of models is required to convert the information from monitoring programmes into an assessment of dose to members of the public. When environmentally dispersed radionuclides are ingested or inhaled, models are required to describe and quantify environmental transfer processes as well as the biokinetics of the radionuclides in the human body and the associated dosimetry.

502. Where the doses are expected to be well below dose constraints, it is adequate to make an estimate based on simple models and conservative assumptions. When doses may exceed a small fraction of authorized levels, more refined models and realistic parameters are required. In general, the closer to man that the measurements are made, the simpler the model required.

503. Assessment of doses from a particular source is dependent upon models representing the pathways between the source and the exposed individuals. Where environmental monitoring permits the impact of that particular source to be evaluated, the dose assessments may be supplemented by environmental measurements. For comparison with constraints, models should relate to real or postulated critical groups.

504. Environmental measurements generally provide information on activity concentrations in environmental media that may result from a number of sources and thus these measurements may be used for an individual-related dose assessment.

### 5.1.1. Specific activity models

505. The specific activity methodology for calculating dose assumes that an equilibrium ratio exists between the radioactive and stable isotopes in the environment and in the human

body tissues at a specified location. This method leads to a particularly simple form of modelling (transfer coefficients are eliminated); it can be employed in the case of long-lived radionuclides that are globally distributed and the concentrations vary little with time in the biosphere (e.g. $^{14}C$ and $^{3}H$). However, use of such models may not be valid for locations at close proximity to the source(s).

### 5.1.2. Compartment models

506. Fig. 3 illustrates the importantpathways by which an individual may be ex sed following the release of radionuclides to the atmosphere and the ground or surface water, respectively. Doses can be calculated by means of compartment models if there is adequate knowledge of routes and rates of transfer of materials between compartments. These relationships can be expressed by equations that can be solved analytically for simple systems or numerically for complex systems. In some situations, where information on the time dependence of activity concentrations is not required and it may be assumed that a state of dynamic equilibrium exists, the concentration in the compartment of interest may be estimated from that in a different compartment by means of the appropriate concentration factor.

### 5.1.3. Physical models

507. Environmental physical transfer processes, such as dispersion of radionuclides discharged to the atmosphere and diffusion and advection in the seas and oceans can be represented by models chosen to simulate the real transfer mechanisms believed to be involved. More details on these models y can to be found in Refs. [33-35].

### 5.1.4. Biokinetic and associated dosimetric models

508. The Basic Safety Standards [4] and ICRP Publication 61 [36] gives values of *committed effective dose* per unit intake and *Annual Limits on Intakes* (ALIs) for adult

workers based on Reference Man and dosimetric models, but only provisional guidance is given on calculating the values of committed effective dose per unit intake for the public. Account should be taken of any differences from Reference Man in respect of sex, age, organ size and metabolic parameters if the calculated or estimated committed effective dose per unit intake approaches the constraint or dose limit. Allowance may also be made for the physical and chemical form in which the radionuclides are present in the environment. ICRP is currently preparing guidance on age-dependent doses to members of the public from intake of radionuclides, and partly published in ICRP Publication 56 [37] for a limited number of radionuclides.

### 5.1.5. Determination of environmental models

509. The simplest model that provides a sufficiently accurate estimate of the parameter to be evaluated should be chosen. Safety Series No. 77 provides additional information on the application of these models for limiting dose [6]. The quantities ultimately required from monitoring and modelling are doses and committed doses from specified sources to members of critical groups or the corresponding collective quantities for larger population groups. In addition, models are described by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [1], by the ICRP [38], and by the IAEA [23].

510. All models are to some degree based upon observations; the parameters used in them should be verified experimentally if validity for a given purpose is claimed. When models are used entirely or in part to estimate doses from practices some verification by the regulatory authority should be attempted before the practice is introduced. When the practice has commenced, the monitoring programme may be implemented to achieve further verification. A less complex programme is sufficient when verification is satisfactory.

## 5.2 EXTERNAL AND INTERNAL DOSE ASSESSMENT

### 5.2.1. Dose from external irradiation

511. The assessment of doses is simplest in principle when the only exposure pathway is by external irradiation. When the source is discrete, the radiation field in its vicinity should be measured or calculated. To determine the *effective dose* to the *critical group*, calculations should be made to allow for the effects of distance, shielding and scattering. A knowledge of the time spent by the critical group in the vicinity of the source is needed if dose assessment is to be realistic. If all that is required is a demonstration of compliance with dose constraints, it is sufficient to calculate the effective dose to a hypothetical individual at the boundary of the site. When external dose results from dispersed radionuclides, for example activity deposited on the ground, models are available to calculate effective dose rates from measured activity concentrations [39]. Assumptions or observations on relevant habits are again necessary if the assessment of effective dose is to be realistic.

### 5.2.2. Dose from intakes of radionuclide

512. *Committed effective doses* from inhalation or ingestion of radionuclides are estimated from a knowledge of activity concentrations in air and foodstuffs and by use of appropriate intake rates as well as appropriate biokinetic and dosimetric models.

# 6. RECORDING AND REPORTING OF RESULTS

601. The recording and reporting of measurement results and related information should satisfy the objectives of the monitoring programme. These objectives may require calculation of critical group and collective doses or merely a comparison of measured values with appropriate derived levels.

## 6.1 RECORDING AND REPORTING OF SOURCE AND ENVIRONMENTAL MONITORING RESULTS

602. In accordance with the BSS, *registrants and licensees, during the operational stages of sources under their responsibility, shall:*

*(a) record the monitoring results and estimates exposures;*

*(b) report the monitoring results to the regulatory authority at approved intervals; and*

*(c) report promptly to the regulatory authority any discharges exceeding the authorized discharge limits in accordance with reporting criteria established by the regulatory authority [p. 61].*

603. The main purpose of recording source monitoring data is to permit an estimate of external dose rates or quantities of radionuclides released. Source monitoring data must be presented in terms which can be directly compared with the prescribed limits. In general, for airborne and liquid discharges, this will be the total activity of each radionuclide released by each route during the reporting period. If activities are expressed in terms of gross beta or gross alpha, an indication of typical radionuclide composition should be given. However, this type of reporting should be avoided as far as possible because of the inherent uncertainties in the interpretation of the results. Alternatively they can be expressed in terms of the most restrictive radionuclide that might be present in the mixture.

604. Environmental monitoring data may be used to estimate doses to critical groups or population, and to indicate trends in environmental levels. The record-keeping system should be designed to keep as much basic information as may be required for both purposes. However, detailed results must be reported in a way that provides a check on normal operations and gives early warning of departures from normal.

605. Valid assessment of releases requires statistical analysis of data to detect any trends and resolve anomalies. It may be difficult to distinguish anomalies due to operational factors from normal variations in the source and measurement system. The use of sequential plotting, central charts, and monitoring data are useful tools to be correlated with other information on the operation of the facility.

606. The way in which results are reported must be related to the objectives of the monitoring programme. In some circumstances it may be adequate to compare measured dose rates or activity concentrations with appropriate derived levels; in other case, it may be necessary to evaluate doses to critical groups and the collective dose to the population. Nevertheless, these doses should be reported and compared with dose limits as set down in the Basic Safety Standards or dose constraints specified by the regulatory authorities. The methods used to calculate doses and the other parameters required should also be reported.

607. In view of the increasing public awareness of environmental issues, it is recommended that all environmental monitoring programmes and results should be reported with adequate explanation of their significance.

## RETENTION OF RECORDS

608. *Registrants and licensees shall keep appropriate records of the results of these monitoring programs [BSS p. 61].* The Regulatory Authority should specify the retention period for source and environmental monitoring records in their regulatory requirements.

# 7. QUALITY ASSURANCE

701. Quality assurance may be describe as comprising those planned and systematic actions that are necessary to provide adequate confidence in the results of a monitoring programme. All monitoring programmes must be subject to adequate quality assurance arrangements. Quality assurance is an essential aspect of "good management". Good management contributes to the achievement of quality through thorough analysis of the tasks to be performed, identification of the skills required, the selection and training of appropriate personnel, the use of appropriate equipment, the creation of a satisfactory environment in which activity can be performed and a recognition of the responsibility of the individual who is to perform the task. Briefly stated, then, a quality assurance programme should provide for a disciplined approach to all activities affecting quality, including, where appropriate, verification that each task has been satisfactorily performed and that necessary corrective actions have been implemented. It must provide for production of documentary evidence to demonstrate that the required quality has been achieved. However, quality assurance can be costly; the effort devoted to quality assurance for a particular measurement procedure should be commensurate with the importance of that measurement within the monitoring programme.

702. An adequate quality assurance programme must be designed to ensure that:

(a) *for purposes of monitoring and verification of compliance, suitable equipment shall be provided and verification procedures introduced,* documented and implemented *[BSS p. 27]*;

(b) *equipment* and instruments *shall be properly maintained and* periodically *tested* to ensure that they function correctly *[BSS p. 27]*;

(c) analyses (including sample preparation) are well documented and correctly performed;

(d) records are maintained as required by the management and by the regulatory authorities;

(e) uncertainties in results are quantified to the extent possible and are documented.

703. Quality assurance applies to all stages of a monitoring programme:

(a) *Laboratory equipment* and calibrations standards *shall be properly maintained and tested and shall be traceable to national or international standards*, or should be calibrated against such standards *[BSS p. 27]*. They should be stored under suitable conditions and replaced as necessary. Laboratory standards and calibration certificates should be properly documented;

(b) Sampling procedures should be designed to be representative. They should be well-documented and reproducible;

(c) Samples should be prepared for analysis in such a way that any loss of activity is accounted for, and no cross-contamination occurs. In addition, in some selected situations, samples may be needed for archival purposes and should be properly stored;

(d) Radiochemical separation procedures should be validated and documented. Any departures from normal procedures should be noted;

(e) Measurement equipment should be subject to a periodic programme of checking background and calibrations;

(f) Measurement results should be presented in a uniform manner. Uncertainties due to the random nature of radioactive decay should be calculated and expressed in a uniform way. Other uncertainties should be quantified where possible;

(g) Staff should be well-trained and motivated.

704. The quality of results should be demonstrated by:

(a) a programme of measurement of suitable blank and reference samples;

(b) the inclusion of replicate samples in the measurement programme;

(c) inter-laboratory comparison of methods and instruments on national or international base.

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## CAPTIONS OF FIGURES

FIG. 1 Example design of an environmental monitoring programme for a major source (from Ref. [2]).

FIG. 2 Simplified pathways to man from radioactive materials released to atmosphere (from Ref. [2]).

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Figures for a draft of monitoring Guide.

Fig.1. Types of monitoring for radiation protection of the public.

Fig.2. Basic Scheme for source and environmental monitoring for radiation protection of the public.

Fig. 3. Simplified pathways to man of radioactive materials released to the atmoshere or water bodies.

Fig. 4. An example of design of an environmental monitoring programme for a major source (from Ref. [2] ).

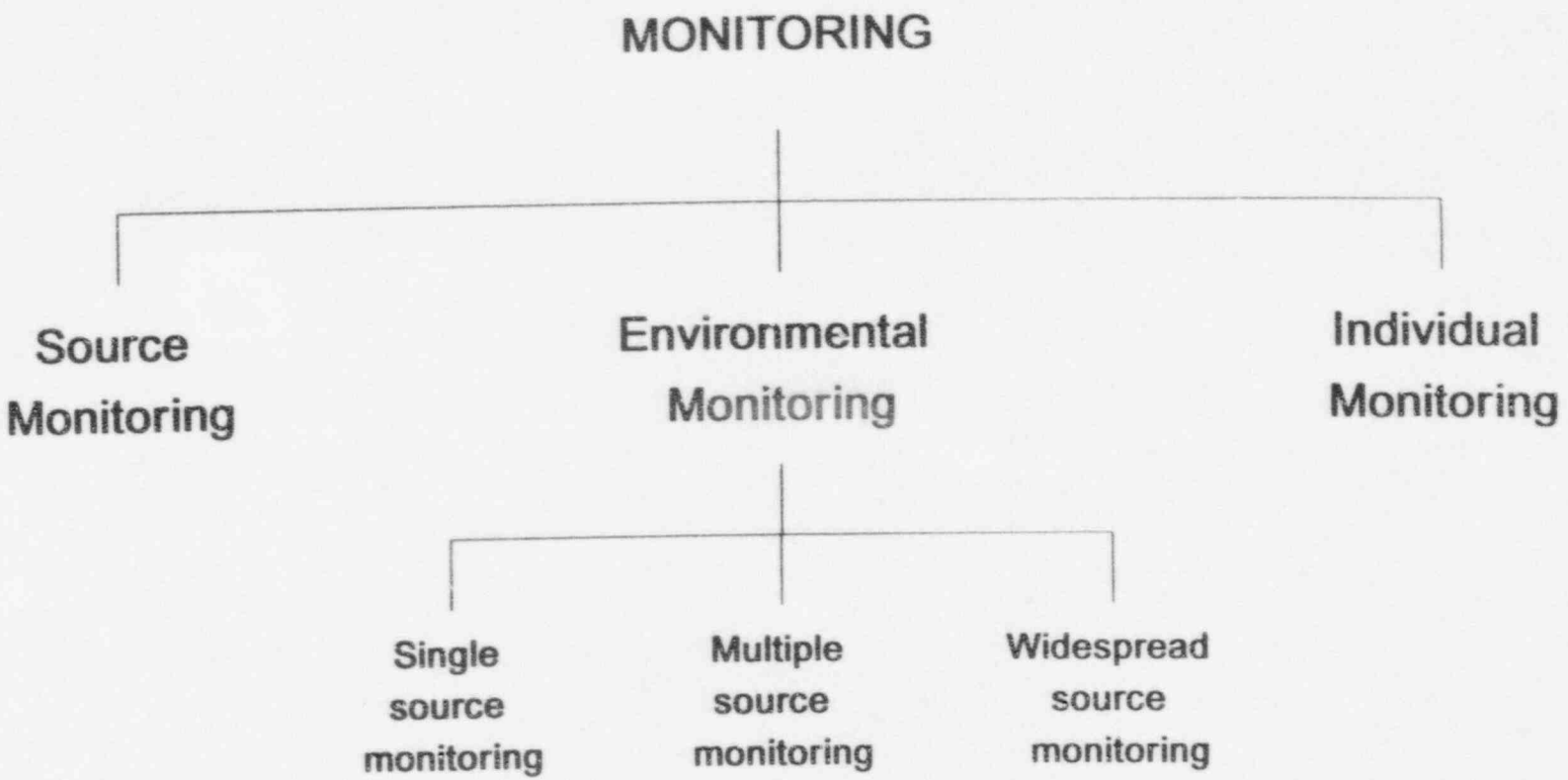



Fig. 1. Types of monitoring for radiation protection of the public

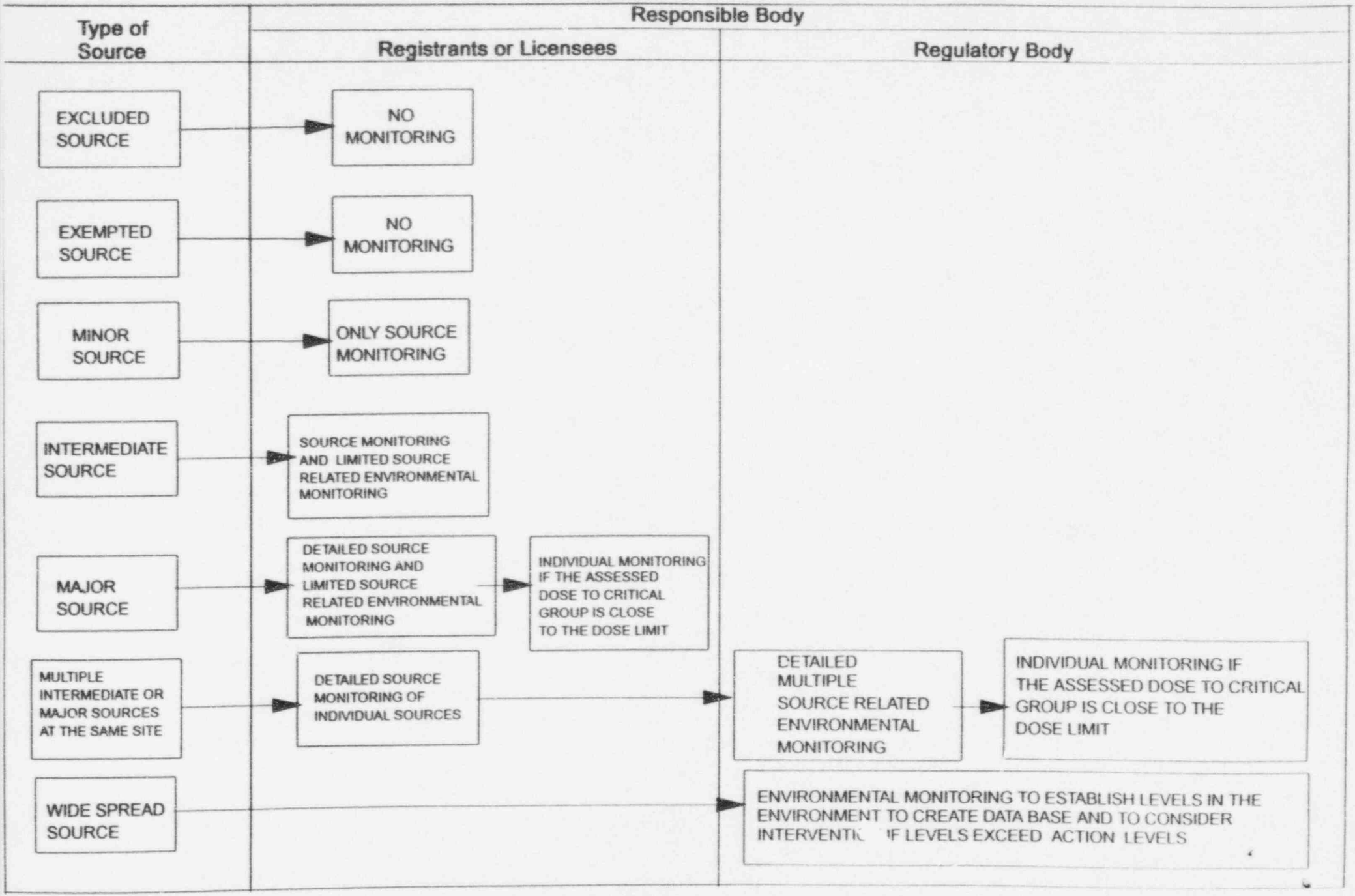
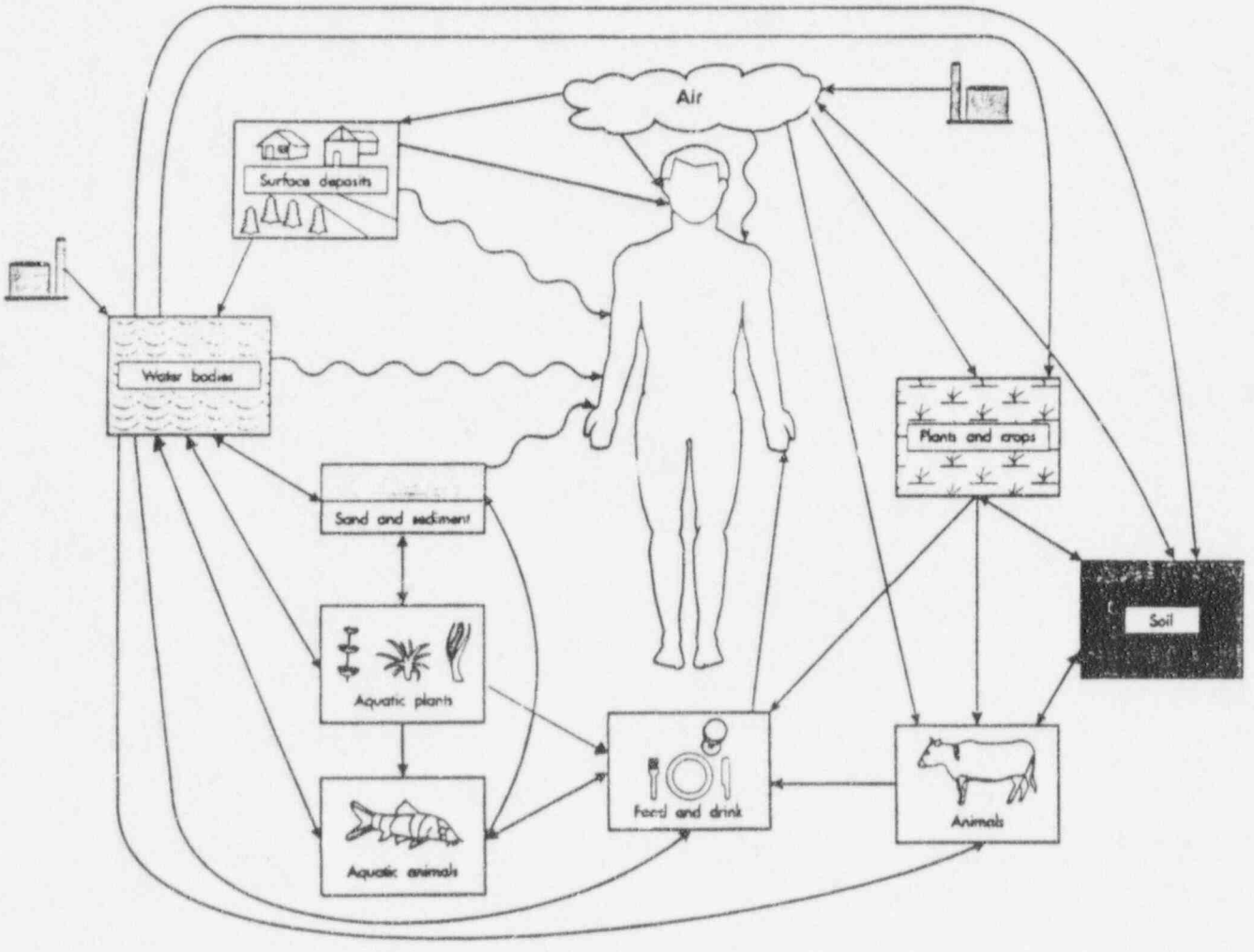



Fig. 2: Basic Scheme for Source and Environmental Monitoring for Radiation Protection of the Public

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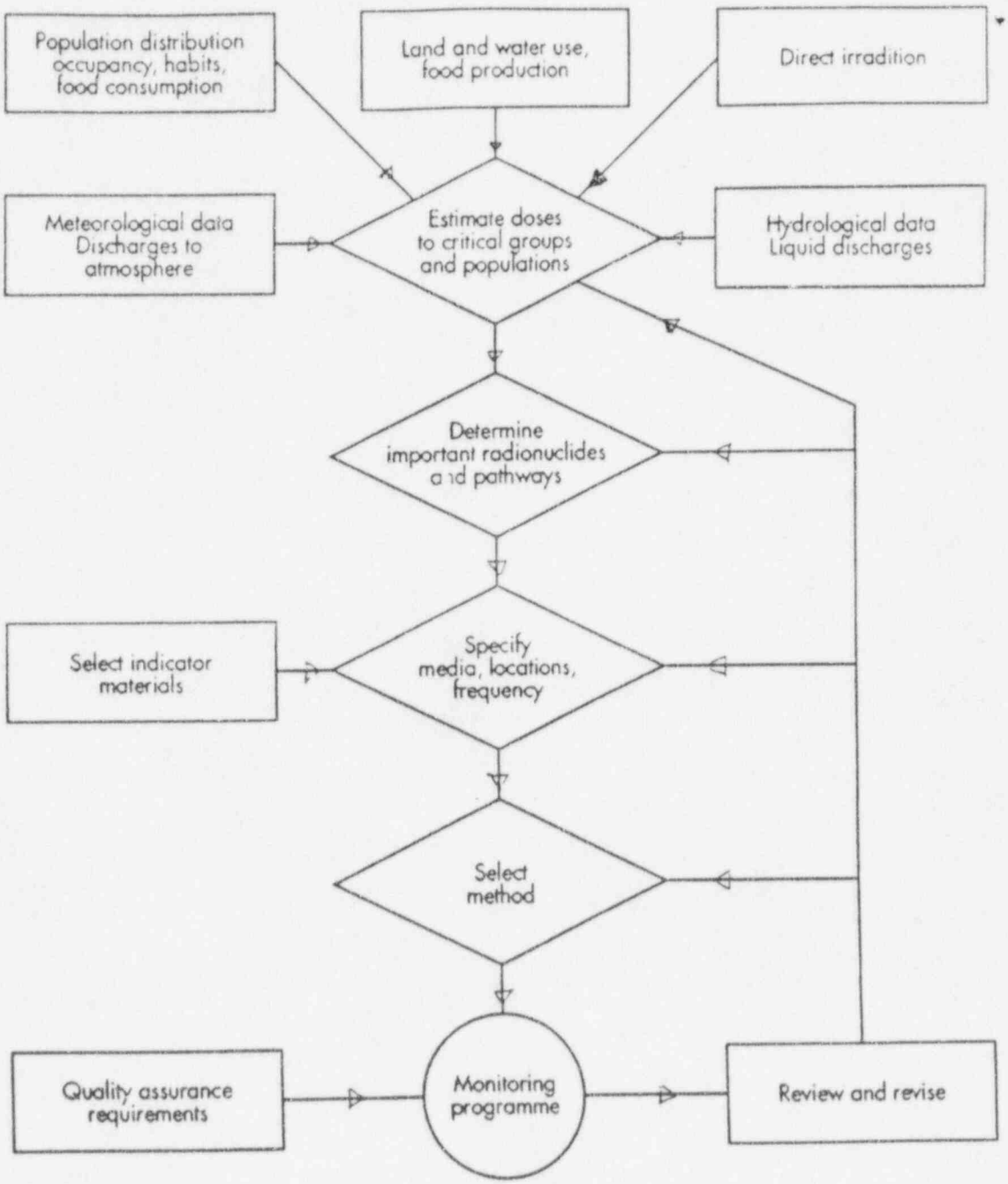


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