

***Rapid monitoring of
large groups of
internally contaminated people
following a radiation accident***



INTERNATIONAL ATOMIC ENERGY AGENCY

IAEA

The IAEA does not normally maintain stocks of reports in this series.
However, microfiche copies of these reports can be obtained from

INIS Clearinghouse
International Atomic Energy Agency
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna, Austria

Orders should be accompanied by prepayment of Austrian Schillings 100,—
in the form of a cheque or in the form of IAEA microfiche service coupons
which may be ordered separately from the INIS Clearinghouse.

The originating Section of this document in the IAEA was:

Radiation Safety Section
International Atomic Energy Agency
Wagramerstrasse 5
P.O. Box 100
A-1400 Vienna, Austria

**RAPID MONITORING OF LARGE GROUPS OF INTERNALLY CONTAMINATED PEOPLE
FOLLOWING A RADIATION ACCIDENT**

IAEA, VIENNA, 1994

IAEA-TECDOC-746

ISSN 1011-4289

Printed by the IAEA in Austria
May 1994

FOREWORD

The widespread use of atomic energy and different sources of ionizing radiation in medicine and industry carries with it a small but finite risk of accidental release of radioactive substances to the environment. Such a release may cause radioactive contamination at regional and even global levels and may require rapid and special response to assess and mitigate potential exposure of workers at the nuclear installation and of the general public.

In the management of an emergency, it is necessary to assess the radiation exposures of people in the affected areas. An essential component in the programme is the monitoring of internal contamination. Existing fixed installations for the assessment of incorporated radionuclides may be of limited value in these circumstances because they may be inconveniently sited, oversensitive for the purpose, or inadequately equipped and staffed to cope with the large numbers referred to them.

During the assessment and remedial actions taken following the Chernobyl and Goiânia accidents, experience showed that there was an acute need for guidance on conducting large scale individual monitoring of internally contaminated people using simple, readily available equipment and improvised techniques. Suitable equipment is usually available in hospitals, medical research and national radiation protection centres as well as in laboratories associated with the nuclear industry.

The IAEA considered it important to produce guidance on rapid monitoring of large groups of internally contaminated people. The purpose of this document is to provide Member States with an overview on techniques that can be applied during abnormal or accidental situations.

The preparation of this TECDOC is part of the IAEA's response to a recommendation made by the International Nuclear Safety Advisory Group in its Summary Report on the Post-Accident Review Meeting on the Chernobyl Accident in 1986. The IAEA is also preparing three other relevant safety related publications on direct methods for measuring radionuclides in man, assessment of doses to populations and individuals from radionuclides in food, and indirect methods for assessment of incorporated radionuclides in man.

This publication has been prepared from material contributed by the participants of a Technical Committee Meeting which took place in January 1989. Thanks are due to D. Newton, Harwell Laboratory, United Kingdom, A. Andrasi, Central Research Institute for Physics, Hungary, and I. Gusev, Institute of Biophysics, Ministry of Public Health, Russian Federation, who acted as consultants in the preparation of the working paper, as well as in the finalization of the document. The final compilation was the responsibility of A.A. Moiseev of the Division of Nuclear Safety of the IAEA.

EDITORIAL NOTE

In preparing this document for press, staff of the IAEA have made up the pages from the original manuscript(s). The views expressed do not necessarily reflect those of the governments of the nominating Member States or of the nominating organizations.

The use of particular designations of countries or territories does not imply any judgement by the publisher, the IAEA, as to the legal status of such countries or territories, of their authorities and institutions or of the delimitation of their boundaries.

The mention of names of specific companies or products (whether or not indicated as registered) does not imply any intention to infringe proprietary rights, nor should it be construed as an endorsement or recommendation on the part of the IAEA.

CONTENTS

1. INTRODUCTION	7
1.1. General	7
1.2. Purpose	7
1.3. Scope	7
2. MONITORING PROGRAMMES: OBJECTIVES AND DESIGN	8
3. GENERAL REQUIREMENTS	11
3.1. Location of facilities	11
3.2. Control of surface contamination	11
3.3. Manpower resources	12
3.4. Supplies	12
4. INITIAL SURVEY	14
4.1. Requirements	14
4.2. Methods	14
4.3. Calibration	14
4.4. Interpretation	16
4.5. Recording	16
5. INVESTIGATION OF INTERNAL CONTAMINATION AT INTERMEDIATE LEVELS	17
5.1. Requirements	17
5.2. Methods	17
5.3. Calibration	19
5.4. Accuracy	19
5.5. Recording	19
6. INVESTIGATION OF INTERNAL CONTAMINATION AT HIGH LEVELS . . .	21
6.1. Requirements	21
6.2. Methods	21
6.3. Calibration	21
6.4. Interpretation	22
6.5. Recording	22
7. FOLLOW-UP STUDIES	23
7.1. Seriously contaminated individuals	23
7.2. Individuals in the intermediate group	23
7.3. Individuals with low levels of contamination	23
7.4. Monitoring of groups for epidemiological studies	23
REFERENCES	25

ANNEX I. EXPERIENCE IN THE FORMER USSR SINCE THE CHERNOBYL ACCIDENT	27
ANNEX II. MONITORING PROCEDURES AFTER THE RADIOLOGICAL ACCIDENT AT GOIÂNIA, BRAZIL	41
CONTRIBUTORS TO DRAFTING AND REVIEW	45

1. INTRODUCTION

1.1. GENERAL

Major accidental releases of radionuclides have the potential for significant radiation exposure in large populations. In order to properly respond to large scale accidents, planning and identification of resources is important. This Guide is intended to highlight the considerations that must be made in the planning process. The accidents at Chernobyl and at Goiania have shown the need for guidance on the design and rapid implementation of programmes for assessing internal contamination in large numbers of individuals. Illustrations of the monitoring techniques used for these accidents are presented in Annexes I and II.

1.2. PURPOSE

The purpose of this publication is to provide an overview of techniques and methods that can be applied during abnormal or accident situations; and to give practical guidance on conducting large scale monitoring of internally contaminated people using simple, readily available equipment and improvised techniques. This guidance should assist in the advance preparation of emergency response plans and implementing procedures aimed at identifying those most at risk who would benefit from early medical intervention.

This document is intended for institutions engaged in emergency response planning and for personnel in charge of monitoring of internal contamination. Although the guidance is primarily oriented towards specialists experienced in whole body counting it is also intended for those who are knowledgeable in radiation protection but not necessarily specialists in monitoring of internal dosimetry.

1.3. SCOPE

It is not feasible to issue detailed advice for every situation, since the appropriate procedures depend on the radionuclide composition of the contamination and specific local factors and conditions. However, the most probable scenario involves the release of radioactive materials, emitting abundant and penetrating gamma radiation (energy >0.1 MeV) and thus facilitating the direct and prompt assessment of internal contamination by direct measurement. In other, much less likely circumstances, involving widespread contamination with nuclides not emitting energetic gamma radiation, monitoring by excretion analysis may be required. In that situation, the technical and logistical aspects would be quite different, but the general principles for the selection of people for medical intervention and rigorous assessment of internal exposure would remain valid.

2. MONITORING PROGRAMMES: OBJECTIVES AND DESIGN

The International Commission on Radiological Protection (ICRP) has formulated basic principles [1] for planning urgent actions following major radiation accidents, and these have been reflected in the IAEA's Safety Series documents [2-4]. The aims of these countermeasures are primarily to avoid serious deterministic health effects in the exposed population, and to limit the incidence of stochastic effects in the more seriously exposed individuals. The subsidiary aim, of minimizing the collective dose commitment, is of secondary relevance in the present context. In establishing the need for certain countermeasures and in judging their effectiveness, assessments of internal radioactive contamination may be required on a large scale; their purpose *inter alia* would be to identify those most at risk who could benefit from early medical intervention, and those whose lower levels of contamination may, nevertheless, justify a recorded assessment of committed dose.

Existing facilities for monitoring internal contamination, many of which are associated with nuclear installations [5-8], may have a part in large scale, post accident surveys but they might not be suited to the full range and number of investigations required, for several technical and logistical reasons. These include the wide range anticipated in the levels of body burden (perhaps covering several orders of magnitude), with the more sensitive equipment unable to cope with photon fluxes from seriously contaminated people. They include also geographical factors: the facility may be too close to the source of the contamination, or too distant from the place where monitoring is required. Moreover, such establishments might not be able to cope with the demand which, in extreme cases, could require investigation of tens or hundreds of thousands of potentially contaminated subjects.

In this situation authorities must plan to set up, at short notice, independently sited monitoring centres to fulfil certain of the required functions, using equipment which has either been acquired specially for this contingency or which can be diverted from its regular uses without delay. The authorities should also formulate a plan for monitoring which makes the best use of resources in producing the required information as quickly as possible.

Figure 1 illustrates a plan for primary screening of potentially exposed people, using simple equipment such as survey meters. The people are categorized into three groups according to predetermined levels of estimated internal contamination.

- Group I – People with internal contamination below action level A are not of particular concern, but may be monitored at a future stage with more sensitive equipment for statistical or epidemiological purposes.
- Group II – People with internal contamination between action levels A and B in the initial survey would be directed to separate facilities for more thorough evaluation, including gamma ray spectrum measurement.
- Group III – People with internal contamination above action level B are referred to specialists for prompt, accurate assessment with gamma ray spectrometers suited to investigate high levels of contamination, and if appropriate medical treatment.

Only general guidance can be given for setting action levels A and B. A sound approach is to relate them to corresponding levels of committed effective dose (CED). If,

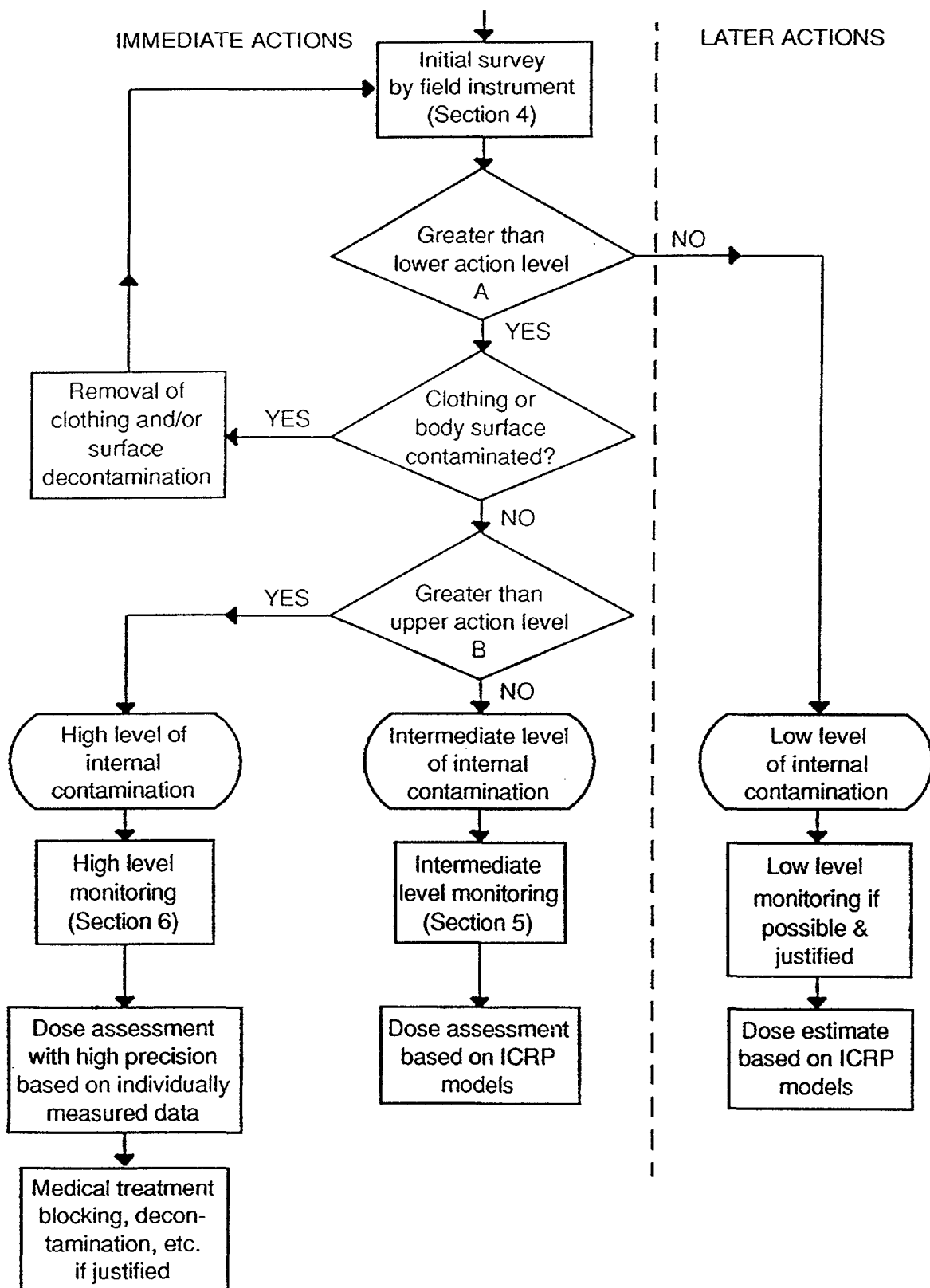


FIG. 1. Recommended procedures for monitoring.

for example, CED values of 0.5 mSv and 50 mSv¹ are selected as appropriate decision levels, then the equivalent internal contamination levels (action level) are established accordingly.

To illustrate, in the case of ¹³⁷Cs, level A would be 5×10^4 Bq. Several days after intake, this would give an indication of about 0.05 μ Gy/h on a survey meter placed 1–2 cm from the body. Under typical conditions, this is roughly equivalent to a 50% increase in background. Level B would be 5×10^6 Bq, resulting in a dose rate under equivalent conditions of 5 μ Gy/h. The arbitrarily chosen decision level in this example, $A' = 0.5$ Sv, may be unnecessarily restrictive. Such a conservative approach allows for the large uncertainties which exist in the actual correspondences between A' and the estimated value of A (and between B' and B). These relationships would depend not only on factors relating to the measurement, but also on aspects of the individual's metabolism, the circumstances of the intake, and where a mixture of radionuclides was present, on its composition. Moreover, there may be situations in which a given level of internal contamination, insignificant in itself, implies the possibility of significant external irradiation. In practice, the initial choices of decision level A' and B' , and of the action levels A and B derived from them, may need to be reviewed according to the measurement range of available equipment and the capacity of the more rigorous monitoring arrangements in relation to the demands made on them.

¹ The numerical values of CED (committed effective dose) for levels A and B are given here only as examples and in every particular case they should be established by the authorities taking into account all complexities of radiation, social and economic factors.

3. GENERAL REQUIREMENTS

3.1. LOCATION OF FACILITIES

The monitoring facilities needed to carry out the actions illustrated in Fig. 1 do not necessarily have to be located in the same building and perhaps not even in the same area of a town or city. Each of the three categories of monitoring equipment (Sections 4, 5 and 6) should be sited where the levels of natural background radiation are not unusually high and where they have not been unduly supplemented by contamination from the incident. In this latter regard, the situation may deteriorate with subsequent meteorological changes. Existing fixed facilities would often be equipped with heavy shielding and filtered air supplies, so that local particulate contamination might be tolerated, provided the installation remained accessible.

The preliminary screening and classification should be performed in an area appropriate to the potential demand, and large enough to permit adequate separation between (i) people awaiting initial monitoring, (ii) those being monitored, (iii) those awaiting transfer for further assessment and (iv) temporary collections of contaminated clothing. Public facilities such as sports centres and arenas are likely to be suitable, with the required shelter or space in which to instal monitoring facilities, electric power supplies, sanitation and communications; showers for removal of loose surface contamination must be improvised if not already installed. Hospitals may offer these and other useful facilities, but should possibly be responsible for screening only those with injuries; a wider role might interfere with communications and overload their resources, impeding the treatment of injured or seriously contaminated people.

However, a hospital or other medical centre would be the logical choice for siting "high level" monitoring equipment (Section 6) since many of those referred would require treatment or qualified advice, and those detained may need further access to such equipment during their treatment. Hospitals might also accommodate the "intermediate" level monitoring, since suitable equipment could already be in situ, provided the presence of seriously contaminated patients housed nearby did not interfere with the assessments.

3.2. CONTROL OF SURFACE CONTAMINATION

Account must be taken for monitoring procedures, particularly in the initial screening, of the possibility of spurious assessments because subjects have imported loose surface contamination, and precautions are required to ensure its ready removal if it occurs. The initial screening should take place inside tented areas with replaceable surfaces, which subjects would enter after removal of shoes. The monitoring probe should be protected from contamination and staff should wear disposable clothing. For subjects showing levels $>A$ the next stage (Fig. 1) would involve showering and a change of clothing, before remonitoring, which should preferably be undertaken with duplicated facilities to avoid any risks of recontamination. The discarded clothing should itself be monitored, and if found to be unacceptably contaminated for further everyday use it should be held in a separate, designated area pending disposal. Clothing contaminated at lower levels may need to be withheld from subjects referred for more rigorous assessment, in order to avoid complicating those operations. Contamination of the body surface which cannot readily be removed should be reported to medical authorities and also, if appropriate, to the centre responsible for the further stages of monitoring (Sections 5 and 6).

Control would obviously be necessary also at centres for the further monitoring of those referred after initial screening. Its extent would depend on contamination of the local environment and on the procedures for transferring people from the screening centres. As a minimum, however, the precautions would include the wearing of shoe covers and fresh outer garments by staff and subjects to be measured, and readily renewable protection of detectors and their environs. It may be impossible to avoid the effects of fluctuating airborne contamination: many such installations would lack effective shielding, few would be supplied by filtered air and none is likely to be immune from ingress of radioactive gases. In this situation it would be advisable to make frequent brief checks of the background response, a precaution which would also register contamination spreads from the person.

3.3. MANPOWER RESOURCES

The initial screening assessments could be performed by technicians trained in the respective basics of radiation protection procedures. However, if necessary, other capable people may be recruited for this purpose, following instruction in the use of field survey meters. They should, however, act under the guidance of qualified health physicists who would also (i) exercise control to contain any spread of surface contamination (ii) supervise the disposal of contaminated clothing and (iii) issue immediate advice to those seriously contaminated as to their responsibilities in minimizing the irradiation of other people. The functions of assembling people into appropriate staging areas, and ensuring that they follow prescribed routes for initial monitoring or transfer to other facilities, may require the presence of personnel obviously in a position of authority, e.g. police or military reserves.

There is clear need for ancillary and supporting personnel in such functions as the issue of clothing, the provision of food and drink, direction of communications with other centres and interactions with the media. Trained counsellors may be required to ease what for some will be a traumatic experience, irrespective of the outcome.

The more detailed investigations (Sections 5 and 6) should be made by, or under the supervision of, qualified scientists experienced in nuclear radiation spectrometry, who should have access to the advice of a specialist in the measurement of body radioactivity. In some countries there may be few people with the necessary experience. They may need to divide their attentions between their established installations and one or more emergency centres. In such circumstances, efforts should be made to engage foreign specialists. These specialists should have ready access to the regulatory or emergency body overseeing the operation, with a view to securing changes in the action levels A and/or B according to the centres' collective abilities to meet the demand.

The training of scientists and technicians specifically to respond in a postulated emergency, and the occasional practice exercises necessary to reinforce the training and to assess its effectiveness, may be viewed as unjustified in relation to the likelihood of the emergency. In that case, periodic critical assessments should be made of the extent to which existing resources of manpower and expertise could be assembled at short notice and function effectively.

3.4. SUPPLIES

The operation would call for many everyday consumable items on a large scale, and also possibly for the rapid relocation of certain expensive items of equipment. Again, outside help should be sought if national specialized equipment resources prove inadequate. Among

the more obvious consumable requirements would be food and drink for those awaiting initial monitoring or detained as a result, and plastic sheeting to protect monitoring facilities and their environs. There may be need for large quantities of clothing to replace impounded articles, especially in cold weather. Arrangements should be made for mobile generators to be available if local electricity supplies cannot be guaranteed or lack the required stability. The military should be able to respond in this regard, and also in the matter of providing transport and field sanitation, including showers. The field survey equipment envisaged for initial screening should be commonplace items, but this may not be true of equipment required for subsequent monitoring. Therefore, national registries should be maintained of suitable functioning counters which can be requisitioned; also of (preferably) complete assemblies of ancillary electronics and data recording equipment, with details of individual units which could readily be substituted for components which fail.

4. INITIAL SURVEY

4.1. REQUIREMENTS

The purpose of the initial screening, with field survey equipment, is to classify people according to their levels of internal contamination, as a guide to decisions on further action (Fig. 1).

The basic instrument requirements for conducting this screening include adequate sensitivity, portability and ease of handling, continuous operation in the field over extended periods, and positive indication of malfunction. The sensitivity should be adequate to detect the lower level A' of committed effective dose (CED) (Section 2) in any given situation. Survey monitors incorporating scintillation detectors are preferred to Geiger-Müller (GM) detectors. However, if use of GM detectors is unavoidable, the user must be aware that a zero response may result from overloading in a high radiation field from the subject. Instruction in avoiding this situation must be provided.

4.2. METHODS

The equipment should be used with due regard (Section 3.2) to the possibility of spurious results through external contamination, either of the subject or of the immediate environment. To this end, the procedures for dealing with external contamination (Fig. 1) should be followed. The background response of the instrument should be recorded both prior to, and periodically during, the daily monitoring programme.

The procedures suggested here relate to the case of contamination which is likely to be widespread in the body, with no major concentration in any specific anatomical region. The required modifications where there is highly localized radionuclides, as with deposits of radioiodine in the thyroid, are self-evident.

Subjects should enter the monitoring area individually. The instrument should have been calibrated (Section 4.3) in terms of body (or organ) content, both when situated in contact with the appropriate region and at a series of increasing distances from it; in the case of nuclides that are expected to be widely dispersed in the body, the abdomen is suggested as a suitable choice. Initially the probe would be situated in contact with the subject's abdomen. If a positive response were obtained, it would be moved to the largest distance for which both (i) a statistically adequate response could be recorded and (ii) calibration had been established. Measurements at increasing distances are particularly important when the survey monitor is a GM detector, to exclude the possibility of overloading effects (Section 4.1). Where the chosen position was close to the subject, the effect of the body in modifying the background should be considered. As a check of localized surface contamination, a rapid scanning of the most likely regions (head, feet, hands) may be appropriate.

4.3. CALIBRATION

The meter response should be evaluated (1) over the relevant range of energies, (2) for a series of locations in contact with the chosen region of the body and (3) at distances up to several metres from the body and (4) with radioactive sources whose activities are known relative to those of traceable standards.

DATA SHEET

Name:.....

Date of birth:

Address:.....

.....

.....

Remarks:

.....

.....

Type and serial number of the monitor:

Lower action level: kBq

Upper action level: kBq

Measurement:

Date DD/MM/YY	Time HH:MM	Distance [cm]	Reading with subject [.....]	Background reading [.....]	Net reading [.....]	Calibration factor [...../kBq]	Activity [kBq]

Recommendations:

.....

.....

Date:

Analyst:

**Non-removable body
surface contamination**

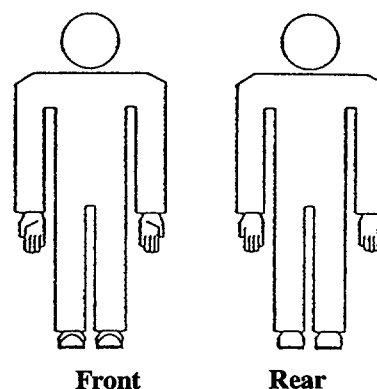


FIG. 2. Suggested data sheet for initial survey.

A single point source of a given nuclide, in some suitable absorbing medium, may suffice at the larger distances. However, in closer proximity a whole or partial body phantom with a crude simulation of the presumed distribution of the radioactive material may be required. To guard against error through instrumental drifts or other causes, the continued validity of the calibration should be confirmed several times daily by reference to the response of a point source in fixed reproducible geometry. This source should be robust so that leakage will not occur.

4.4. INTERPRETATION

It must be recognized that this crude approach to monitoring is not amenable to reliable calibration in terms of body or organ content and that the possible range of actual contents leading to a given estimate may span an order of magnitude. The correct classification of a subject with activity assessed as $>A$ would be confirmed only after more rigorous investigations as indicated in Fig. 1.

4.5. RECORDING

A suggested form for records is given in Fig. 2. The data should include at least the subject's name, date of birth and address, the date and time of the measurement, the type and serial number of the meter, the reading and the conditions under which it was obtained, an indication of the location of any residual body surface contamination, and the recommendation for any further action. Confidentiality should be maintained.

5. INVESTIGATION OF INTERNAL CONTAMINATION AT INTERMEDIATE LEVELS

5.1. REQUIREMENTS

Subjects whose level of internal contamination was initially assessed in the activity range A–B (Section 3) would be referred for more rigorous assessment by appropriate methods. This section is concerned with equipment and procedures for this application.

The range of activities in the intermediate level depends on the setting of the action levels A and B. The appropriate equipment depends in addition on the decay properties of the nuclides present. For the purpose of this Guide, it is assumed that body contents in the range 10^4 – 10^7 Bq are involved, and that there is abundant gamma radiation at energies >0.1 MeV. If the gamma ray fluxes are well outside this range, alternative arrangements may be required. These might involve use of high level monitoring procedures (Section 6) or conversely referral to an established laboratory equipped for the measurement of body radioactivity at low levels.

Within the intermediate range, highly sensitive detectors are not required, and extensive shielding would be of advantage only if there is contamination of the local environment. Important attributes for the counting equipment would be: (1) transportability; (2) flexibility in adapting the mechanical arrangements to individual requirements (e.g. in monitoring either the whole body or specific regions); (3) the ability to process subjects in rapid succession and (4) prompt data evaluation. If a mixture of radionuclides is present, the procedures should include recording of gamma ray spectra and assessment of individual nuclides rather than merely of total gamma activity, unless a specific radionuclide composition could reliably be assumed. The aim should be for accuracy to within a factor of two, at least in the initial assessment. It may be possible to refine the initial estimates subsequently (Section 7).

5.2. METHODS

Several commercial systems exist for the rapid monitoring of the whole-body in a routine, radiological protection context. These may consist of a booth in which the subject stands upright in front of, or possibly between, arrays of stationary detectors. In other designs a single detector may perform a scan of the body, with the possibility of delivering crude indications of how any internal contamination is distributed. The potential usefulness of such devices would depend principally on the scope of any integral data accumulation and processing facilities, or of any such facilities which could be provided. If installed software is employed to produce estimates of body content based on a built-in library of calibration spectra, the validity of the calibration needs to be assessed in relation to the particular conditions of measurement.

Some organizations have monitors installed in vehicles for regular monitoring of workers. These monitors could conveniently be brought into service. They often require the subject to recline on a motorized bed which is slowly moved under a detector housed in a shielded turret. The speed of movement may be geared to the assessment of activities at low levels and the scanning time may therefore be inconveniently long, unless some modifications are made to the mechanism.

As an alternative to importing dedicated or established facilities, arrangements may be improvised, making use of any suitable scintillation counter (including possibly a gamma

camera with collimator removed) [9] or large semi-conductor (germanium, etc.) detector. These arrangements can be made sufficiently flexible to allow (i) for adjustment of the detector-subject disposition in optimizing count-rate and accuracy and (ii) for collimators to be fitted where activity must be assessed in specific organs.

Various possibilities exist for assessment of whole-body contamination. They include:

- (i) arc geometry: the subject reclines on a curved bed so that all parts of the body are roughly equidistant from a detector located at 1-2 metres distance;
- (ii) simpler arrangements, in which the subject stands or lies with the abdomen located on the axis of the detector at 1 metre (or greater) distance.
- (iii) chair geometry: the subject is seated with the detector located at (typically) 0.4 m distance from the trunk and thighs.

The approach adopted will be influenced by several factors including the detectors available, the anticipated distribution of radionuclides in the body, the possible need to accommodate sick or injured people and the availability of appropriate shielding. At the lower end of the activity range under consideration (10^4 - 10^7 Bq) partial shielding would be required to achieve adequate statistical reliability in a short counting time. Local shielding of the detector, to the extent possible without impairing its sensitivity to activity in the subject, may be considered. Shielding of the subject, on all sides except that exposed to the detector, is recommended. Particularly in the absence of such shielding around the body, the subject's presence may modify the ambient radiation field, and it may be important to reproduce the relevant conditions when recording the background response. These precautions will include the provision of an appropriate inactive phantom in place of the subject. As a guide to the thickness of such shielding, the aim should be for 50 mm of lead or its equivalent in some other material such as steel. In practice weight limitations may dictate less effective shielding. The frequency of background checks should be chosen taking into account the importance of early detection of surface contamination brought into the shielded region, or of variations in the local background arising from meteorological changes.

If it is necessary to assess the activity of radionuclides in specific organs or regions of the body, the detector used for whole body monitoring may be fitted with a suitable collimator. In the specific case of monitoring the thyroid for radioiodine, it is best to use a small detector (~20 mm dia.), preferably collimated. Suitable materials should be used to shield parts of the body that may have irremovable surface contamination, to avoid spurious assessments of internal contamination. If the affected areas are so extensive that this approach is inapplicable, excretion analysis will be required to provide a basis for the assessment of committed effective dose.

A data processing system based on a personal computer should be used for accumulation, storage and analysis of the spectra. The energy calibration should be confirmed several times daily through the use of a suitable source (e.g. ^{22}Na) emitting photons at two or more adequately separated energies. Procedures are also required to establish the linearity of response with respect to activity up to the highest count rates which the operators will accept before redirecting the subject to the facilities for high level monitoring.

5.3. CALIBRATION

Existing equipment is likely to have been calibrated in advance, although not necessarily for all of the relevant nuclides. However, improvised counting arrangements will need to be calibrated. In either case, it may not be necessary to establish calibration factors directly for each radionuclide present. If interpolation is adequate, calibration factors for gamma rays that cover the range of energies of the unrepresented nuclides can be used. However, if it is essential to employ linear regression analysis to resolve complex spectra with overlapping peaks, a spectrum will be required for each contaminant.

The calibration should be performed with suitable phantoms. In view of the modest requirements for accuracy (factor of 2) the phantom need not be closely realistic. However, some attempt should be made to roughly simulate the relevant conditions of attenuation and scattering, particularly if overlapping features in the body radioactivity spectra are to be resolved. An improvised array of point sources in stacks of polyethylene plates (or in some other suitable structure) may be used to simulate a localized deposit. For activity in the thyroid, a solid neck phantom with a standardized solution contained in an appropriately shaped chamber, or some equivalent arrangement, is suggested. With radionuclides more widely dispersed, active solutions in a series of plastic containers which can be arranged to simulate subjects of various sizes may be used. Where radioactive solutions are employed, they should contain chemical carriers to prevent plating of the active material on internal surfaces.

The continued validity of an adopted calibration should be confirmed daily through measurements of a designated reference point source in a fixed and reproducible geometry. As further confirmation, there should in addition be occasional remeasurements of the response to a phantom containing a single radionuclide.

5.4. ACCURACY

The results, with an estimated accuracy of a factor of 2 or better, are adequate for purposes of calculating the CED for the individual, based on the standard metabolic models provided in ICRP Publication 30 [10], or, in the case of children, on the most recent data available on dose per unit intake for different age groups. There may be a case (Section 7) for more rigorous assessment of internal contamination and ensuing exposure in a representative sub group of those monitored in this programme.

5.5. RECORDING

Unambiguous records of the investigations are required. The following should be regarded as the minimum requirement:

- (i) Name
- (ii) Address
- (iii) Date of birth
- (iv) Sex
- (v) Weight
- (vi) Height
- (vii) Reference number (coinciding or correlating with a reference stored with the spectral data)
- (viii) Date of measurement

- (ix) Identification of measuring device
- (x) Results of measurement
- (xi) Estimated uncertainty.

Space for additional comments, such as information relating the individual to the circumstances of the accident, and in particular concerning any residual surface contamination (e.g. in a form such as is shown in Fig. 2) should be provided. Confidentiality should be maintained.

6. INVESTIGATION OF INTERNAL CONTAMINATION AT HIGH LEVELS

6.1. REQUIREMENTS

Equipment is required to assess internal contamination in subjects whose levels of activity were estimated at >B. This determination may be made either from preliminary screening results (Section 4) or following re-evaluation from 'intermediate' level monitoring results. The latter situation might arise because the subject was indeed contaminated to such a degree as to merit consideration for medical intervention. Alternatively it may arise because the facilities for medium level assessment were not able to accommodate the response from subjects whose burdens approached the action level B.

The basic requirement for high level measurements is a gamma ray spectrometer with a detector which can be located at a sufficient distance from the body that the count rate is at an acceptable level in the presence of abundant gamma ray emission from body contents of 10^6 Bq or greater. A systematic error of up to 20% is acceptable. However, much better precision is necessary when relative activity estimates from sequential measurements are made to establish a retention pattern. The range of measurable activities should overlap with that of the equipment used for intermediate level studies (Section 5). This is necessary to facilitate continuity in the measurement programme used in retention studies, when the decrease in internal contamination dictates the use of more sensitive counting equipment.

6.2. METHODS

In many cases measurements can be made with any available scintillation detector (e.g. 50 mm dia. \times 50 mm thick or larger), located at a large and preferably adjustable (e.g. 1.5–3 m) distance from the body. These will provide adequate statistical precision in a short (few minutes) measurement time, even in the absence of shielding. In extreme cases, there may be an upper limit to the suitable detector size if the response is too great, even with the maximum attainable separation. The high resolution of solid state detectors offers the advantage of separating multiple radionuclides in complex spectra. In addition, they may more easily handle high counting rates than NaI detectors. Shielding is probably unnecessary unless other highly contaminated subjects were likely to be in the vicinity. With a large separation between subject and detector, the position during the course of measurement may not be critical. However, it is important that the counting geometry is reproducible for each subject if serial measurements are to be made. This could be of advantage for injured subjects. For others, the imposition of an 'arc' geometry (Section 5.2), and the averaging of response with the subject facing, alternately, towards and away from the detector, will assist in attaining the specified 20% accuracy. The requirements for supporting signal and data processing equipment and the recommendations for regular confirmation of stability and linearity of response are the same as presented for intermediate level measurements (Section 5.2).

6.3. CALIBRATION

Techniques exist [11, 12] for the rigorous calibration of systems used to assess whole body radioactivity in distant arc geometry. These can provide accuracy within 10 per cent or better, depending on photon energy. The calibration factor is derived from the response of a standardized point source embedded in a stack of absorbing plates with composition similar to tissue (e.g. paraffin wax). The methods described by Lillegraven and Rundo [11],

to determine the appropriate thickness of the stack and the depth of the source in it, are complicated if multiple gamma ray peaks are present. However, these methods should be applicable to the dominant contaminant in a gamma ray spectrum recorded by a semiconductor detector. Alternatively, the simpler techniques indicated previously (Section 5.3) can probably achieve the required accuracy (20%) if applied to the mean response observed with the subject in the two postures suggested (Section 6.2). Whichever method was adopted, its validity might be assessed in selected cases with high levels of contamination, by reference to the reduction in response during periods when excreta were collected and analysed for radioactive content.

6.4. INTERPRETATION

The results of serial assessments in heavily contaminated subjects, with an absolute accuracy of 20% or better, are used to determine the committed effective dose. This determination is based on the individual's actual metabolism of the radionuclide and on his relevant physical characteristics rather than on the parameters used in the ICRP models. They would also provide, in conjunction with the results of excretion analysis, information on the effectiveness of decorporation therapy, if used.

6.5. RECORDING

The recommendations are as set out in Section 5.6.

7. FOLLOW-UP STUDIES

7.1. SERIOUSLY CONTAMINATED INDIVIDUALS

There are actions which may be necessary after the initial period of intensive monitoring of the population. There will be a need for continued surveillance of most members of this group, and particularly of those individuals whose initial levels resulted in medical intervention. The purposes are to (1) establish the CED rigorously, by reference to observed metabolic patterns, rather than to those presumed to be typical, and (2) to assess the effectiveness of the remedial procedures if this is relevant. These investigations should continue beyond the stage at which the activity ceases to be detectable with the facilities used for high level monitoring (Section 6.2). Before that stage is reached, reliable intercalibration with the facilities for intermediate level monitoring (Section 5.3), or preferably with those of a specialized laboratory, should be established. This is done through comparative measurements of the individual subject.

7.2. INDIVIDUALS IN THE INTERMEDIATE GROUP

It was indicated (Section 5.1) that errors of a factor of 2 would be tolerated in the initial assessment of internal contamination in this group. However, it is important to assess the actual level of accuracy retrospectively through a process of comparison with a specialized laboratory, which could include the use of results from contaminated individuals for intercalibration.

7.3. INDIVIDUALS WITH LOW LEVELS OF CONTAMINATION

There may be need for follow up studies (the 'later actions' in Fig. 1) with the low level counting facilities of specialized laboratories, of representative groups, both of subjects initially screened (Section 4) and of those from more distant locations (Section 7.4) who were previously unexamined. The purposes of these measurements include assessment of collective dose equivalent, evaluation of pathways of exposure, assessments of the effectiveness of protective measures to reduce exposure, or the need to provide reassurance.

7.4. MONITORING OF GROUPS FOR EPIDEMIOLOGICAL STUDIES

The principal objective of a monitoring programme will be to identify individuals in a given population who may have been sufficiently highly exposed as to warrant medical intervention or surveillance. This situation was addressed in the previous sections. However, in populations exposed to a lesser extent, it may be sufficient, at least in the first instance, to monitor a representative part of an exposed population or group within that population. This may provide adequate information for epidemiological studies and it will assist in decisions on the need for a more extensive programme. For epidemiological purposes such groups may be designated, for example, according to age, profession, residential area or extent of local terrestrial contamination. Within each of these groups, there may also be "critical" categories, distinguished for example by dietary peculiarities. The number of people sampled from each group or category may necessarily be restricted by the availability of resources or by the extent of co-operation by their members. However, without such constraints the number to be monitored is determined by the total number in each category and by the statistical accuracy required.

REFERENCES

- [1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, *Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning*, Publication 40, Pergamon Press, Oxford and New York (1984).
- [2] INTERNATIONAL ATOMIC ENERGY AGENCY, *Principles for Establishing Intervention Levels for the Protection of the Public in the Event of a Nuclear Accident or Radiological Emergency*, Safety Series No. 72, IAEA, Vienna (1985).
- [3] INTERNATIONAL ATOMIC ENERGY AGENCY, *Derived Intervention Levels for Application in Controlling Radiation Doses to the Public in the Event of a Nuclear Accident or Radiological Emergency*, Safety Series No. 81, IAEA, Vienna (1986).
- [4] INTERNATIONAL ATOMIC ENERGY AGENCY, *Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Technology*, Safety Series No. 91, IAEA, Vienna (1989).
- [5] INTERNATIONAL ATOMIC ENERGY AGENCY, *Assessment of Radioactive Contamination in Man* (Proc. Symp. Paris, 1984), IAEA, Vienna (1985).
- [6] OAK RIDGE ASSOCIATED UNIVERSITIES, Medical and Health Sciences Division, *Current Status of Whole-Body Counting to Detect and Quantify Previous Exposures to Radioactive Material*, Report to the National Cancer Institute, Oak Ridge, TN (1987).
- [7] PALMER, H.E., et al., *Hanford Whole Body Counting Manual*, PNL-6198/UC-41, Pacific Northwest Laboratory, Richland, WA (1987).
- [8] BELLE, Y.S., et al., *Control of Internal Irradiation, 2.1 Direct Methods for Assessment of Gamma-Ray Emitting Radionuclides in the Human Body, Dosimetric and Radiometric Control During Occupational Exposure to Radioactive Material and Ionizing Radiation, Methodological Guidance, Vol. 2 Individual Control, Radiometry of Samples*, Moscow, Energoatomizdat (1981) 54–95 (in Russian).
- [9] SHORT, M.D., RICHARDS, A.R., GLASS, H.I., *The use of a gamma-camera as a whole-body counter*, Brit. J. Radiol. **45** (1972) 289–293.
- [10] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, *Limits for Intakes of Radionuclides by Workers*, Publication 30, Part I, Pergamon Press, Oxford and New York, *Annals of the ICRP* Vol 3. No. 3/4 (1982).
- [11] LILLEGRAVEN, A.L., RUNDO, J., *A systematic arc calibration method for body radioactivity measurement*, Acta Radiol. Ther. Phys. Biol. (NS) **3** (1965) 369–383.
- [12] TOOHEY, R.E., KEANE, A.T., RUNDO, J., *Measurement techniques for radium and the actinides in man at the Center for Human Radiobiology*, Health Phys. **44** Suppl. No.1 (1983) 323–341.

Annex I

EXPERIENCE IN THE FORMER USSR SINCE THE CHERNOBYL ACCIDENT

(This annex has been compiled from material provided by I.A. Gusev.)

I-1. INTRODUCTION

On 26 April 1986 a major accident occurred at unit 4 of the Chernobyl nuclear power station in the Ukraine, resulting in the release of condensable radioactive material with an activity of about 2×10^{18} Bq from the plant. Extensive areas of Byelorussia, Ukraine and Russia have been contaminated up to hundreds of kilometres from the site. Initial estimates of dose to the general public were based on environmental monitoring; later, direct measurements were made of thyroidal iodine-131 and whole body caesium-134 and caesium-137 from dietary intake. At the end of 1987 a total of more than 200 000 people were screened for internal contamination in Belarus, Ukraine and Russia [I-1, I-2].

The information given below deals with the principal methods used to achieve the objectives set out in Section 2 of the main text.

Specialized equipment for body burden measurements was available before the accident in a few scientific centres of the former USSR [I-1]. However, its capacity, location and features were unsuited to requirements of rapid monitoring on a large scale. Consequently it was necessary to employ a wide range of devices drawn from the equipment of radiology centres, nuclear physics laboratories and health physics organizations, including portable field survey instruments [I-3]. Unprecedented difficulties arose, both in executing the programmes of measurements and in their interpretation. The technical problems derived, *inter alia*, from the need to accommodate individuals of all ages and physiques and from the frequent occurrence of elevated local radiation backgrounds.

I-2. MEASUREMENTS OF RADIOIODINE IN THE THYROID

The main types of device employed are listed in Table I-1. The most sensitive were specialized nuclear medicine instruments (Fig. I-1). These showed the lowest levels of minimum detectable activity (MDA), and their collimation made them the least prone to interference from local environmental contamination, including any on the clothing or surface of the body. Their disadvantage lay in appreciable size and mass, which complicated use in field conditions.

The devices most widely used were survey instruments with NaI(Tl) scintillation detectors with digital or pointer indication, working in 'total radiometry' (i.e. responding to a wide range of gamma ray energies) mode. The MDA of such instruments is in the range 1–10 kBq ^{131}I under normal conditions of background (~ 0.1 $\mu\text{Gy/h}$). Fig. I-2 shows the dependence of MDA for ^{131}I in the thyroid on the background gamma ray dose rate, for a typical unit (SRP-68-01) (Fig. I-3). For an elevated background dose rate of ~ 2 $\mu\text{Gy/h}$, the MDA is ~ 100 kBq, and the corresponding uncertainty in the thyroid dose would be 150 mGy. The usefulness of such instruments is therefore restricted to situations where the environmental background is < 2 $\mu\text{Gy/h}$.

Gas detectors were found to be unsuitable in this application, giving systematic errors in the assessed thyroid content of a factor of three or more. This may be connected with

TABLE I-1. TECHNICAL CHARACTERISTICS OF DETECTORS USED IN ASSESSING INTERNAL RADIOACTIVE CONTAMINATION IN THE LOCAL POPULATION FOLLOWING THE REACTOR ACCIDENT AT CHERNOBYL

Unit type	Mass ^a [kg]	Detector size ^b (dia , thickness, mm)	Shielding	Measurement geometry	Signal processing ^c	Throughput measurements/hour	MDA, kBq ^d	Application
NC25, "gamma- thyroid radiometer" [Fig I-1]	120	40, 40	lead collimator	150-200 mm from neck	SCA, digital output	100	1	¹³¹ I in thyroid
SRP-68-01, gamma-dosemeter [Fig I-3]	6	20, 20	none	close to neck close to abdomen	analogue rate meter [wide energy band]	60	6 20	" " " whole body ¹³⁴ Cs + ¹³⁷ Cs
OMEGA 800, medical gamma camera without collimator [Fig I-5]	600	500, 8	none	450 mm above supine thorax	SCA	35	4	" " "
QBM-1A, "quick body monitor" [Fig I-6]	200	0.3 m ² ^e	partial, 8-10 mm Pb	chair	SCA	60	0.5	" " "
WBC 2.5, transportable whole-body counter [Fig I-7]	450	75, 75	partial, 20-50 mm Pb	chair	MCA	36	1	" " "
WBC 2.2, established whole- body counter [Fig I-8]	3500	203, 102	totally enclosed 150 mm steel	chair	MCA	10 ^f	0.04	" " "

^a Includes any supports and shielding ^b Detector is single NaI(Tl) scintillator except where indicated ^c Minimum significant measured activity in counting time available for stated throughput (95% confidence), for radiocaesium the estimate applies to ¹³⁴Cs + ¹³⁷Cs present in relative quantities 1:2 typical of material released from Chernobyl ^d Total surface area of two organic scintillators ^e SCA = single channel analyser, MCA = multichannel analyser ^f Throughput specified in standard operating procedures consistent with the stated MDA, shorter counting times suffice for rapid monitoring

uncertainties in defining the size and location of the sensitive volume and consequently its disposition relative to the thyroid gland.

I-3. MEASUREMENTS OF WHOLE BODY RADIOCAESIUM IN POPULATIONS CLOSE TO CHERNOBYL

Examples of the main categories of equipment are indicated in Table I-1. They include whole body counters already installed at the time of the accident, for routine monitoring of staff in the nuclear industry and for research purposes. Techniques of measurement and calibration data appropriate to adults were therefore available at the outset but generally had to be developed for use with children. These whole body counters usually comprised fixed (i.e. not transportable) installations which limited their usefulness in an initial programme of emergency rapid monitoring.

For these reasons, improvised arrangements (Table I-1) incorporating gamma cameras and other radiology equipment, without additional shielding, were adopted for the programme of rapid monitoring, as also were simple dose rate or count rate meters with unshielded scintillation detectors of various sizes, held close to the anterior or posterior surfaces of the abdomen. With such arrangements the subject's presence could produce a large screening effect on the ambient background, and appropriate simulations with inactive phantoms were required to ensure that the correct background response had been assumed (Section I-5). Figure I-4 shows how the background dose rate affects the MDA of one such simple dose rate meter (SRP-68-01, Table I-1). According to this, the MDA in normal background conditions is around 20 kBq, rising to about 70 kBq for a background gamma ray dose rate of 1 μ Gy/h. This represents the largest background in which such basic equipment is likely to permit adequate assessments of individual and collective internal whole body doses.

I-4. CALIBRATION OF EQUIPMENT FOR RAPID MONITORING

Calibration of the equipment used for estimating ^{131}I in the thyroid was performed with neck phantoms incorporating a point source. In the case of whole body ^{134}Cs and ^{137}Cs assessed with improvised counters (Section I-3), the detection efficiency often varied strongly according to the subject's physique, especially when a single detector was located close to the body. To minimize ensuing calibration errors, phantoms comprising appropriate assemblies of rectangular plastic bottles (1 L) filled with radiocaesium in solution were prepared appropriate to three physiques (infant, juvenile, adult) (Table I-2). Studies with known amounts of radiocaesium administered to volunteers suggested that the use of these phantoms would lead to calibration errors of no more than 20-30% [I-4].

TABLE I-2. CHARACTERISTICS OF CALIBRATION PHANTOMS USED IN THE RAPID ASSESSMENT OF INTERNAL RADIOCAESIUM

Type	Age (years)	Body length (cm)	Body mass (kg)	Average thickness (cm)
Child	2	84	11.6	8.2
Juvenile	10	131	27.6	10.2
Adult	>17	170	70	14.2

Text cont. on p. 39.

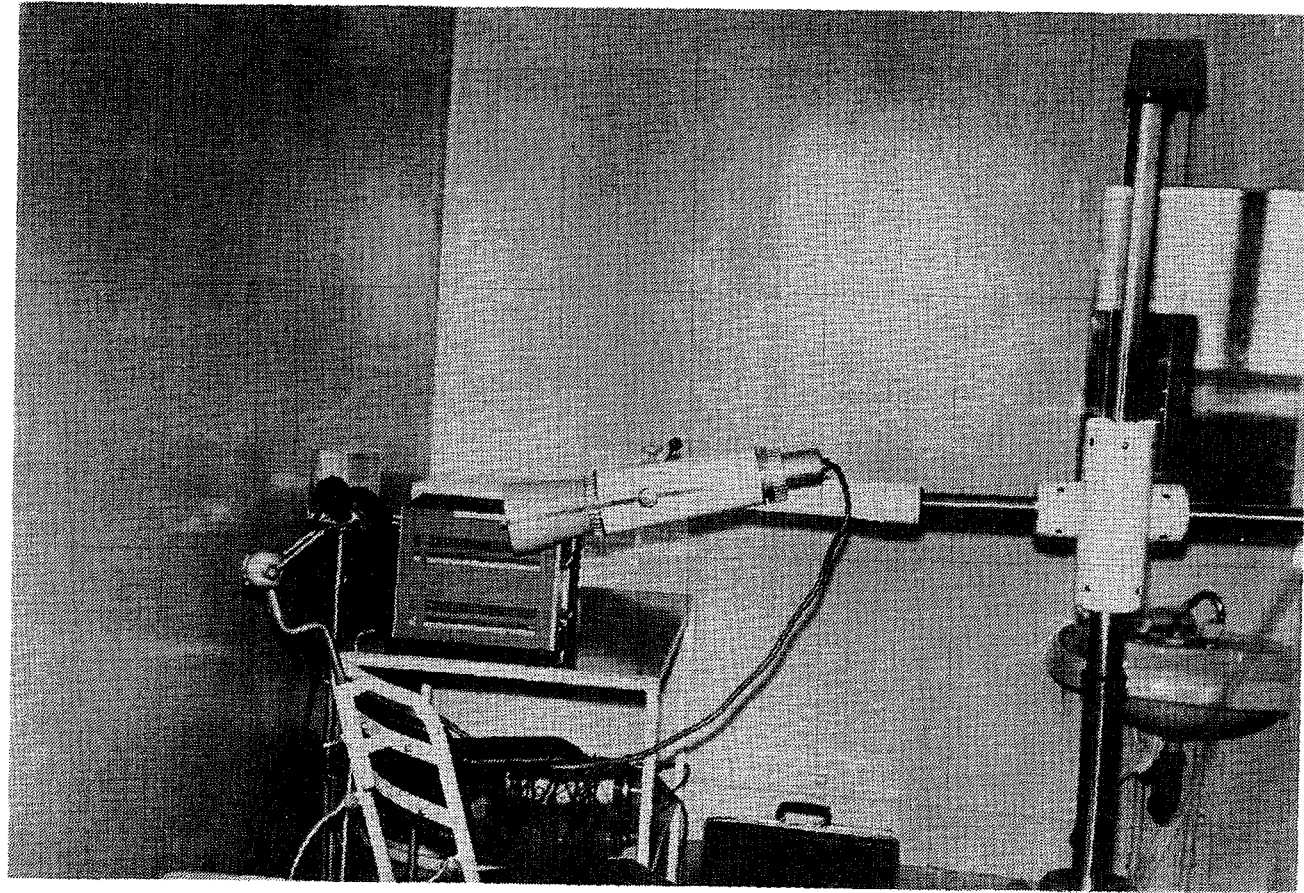


FIG. 1-1. Gamma thyroid radiometer NC-25.

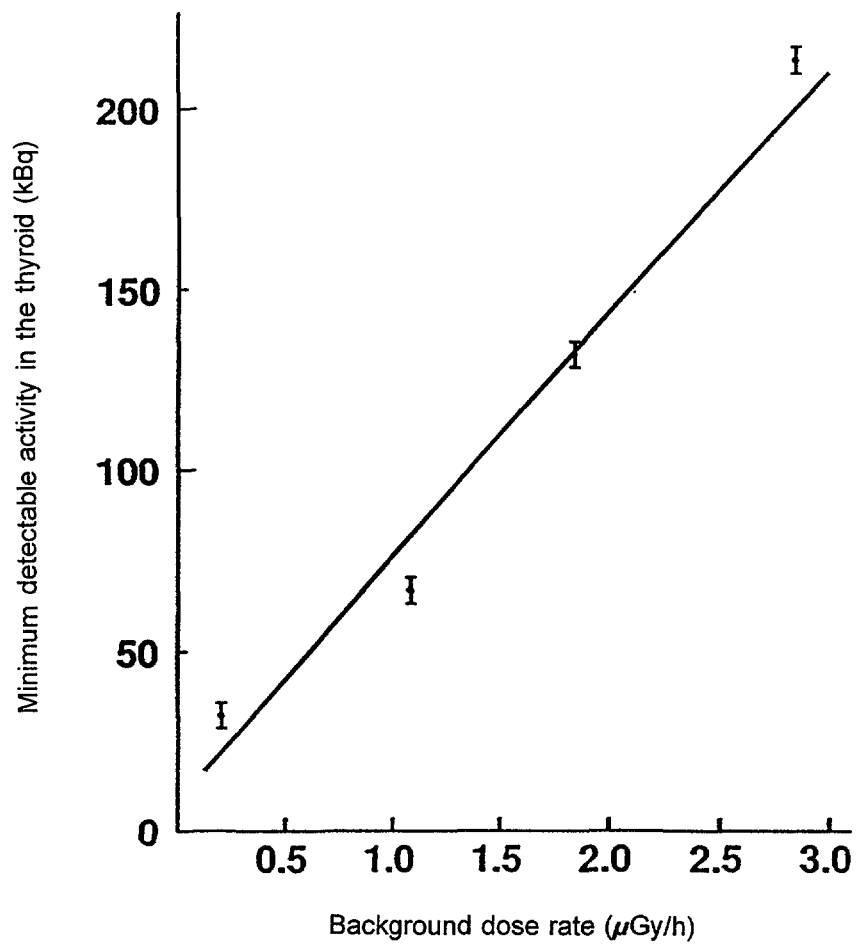


FIG. I-2. Dependence of minimum detectable activity (^{131}I) on the background dose rate.

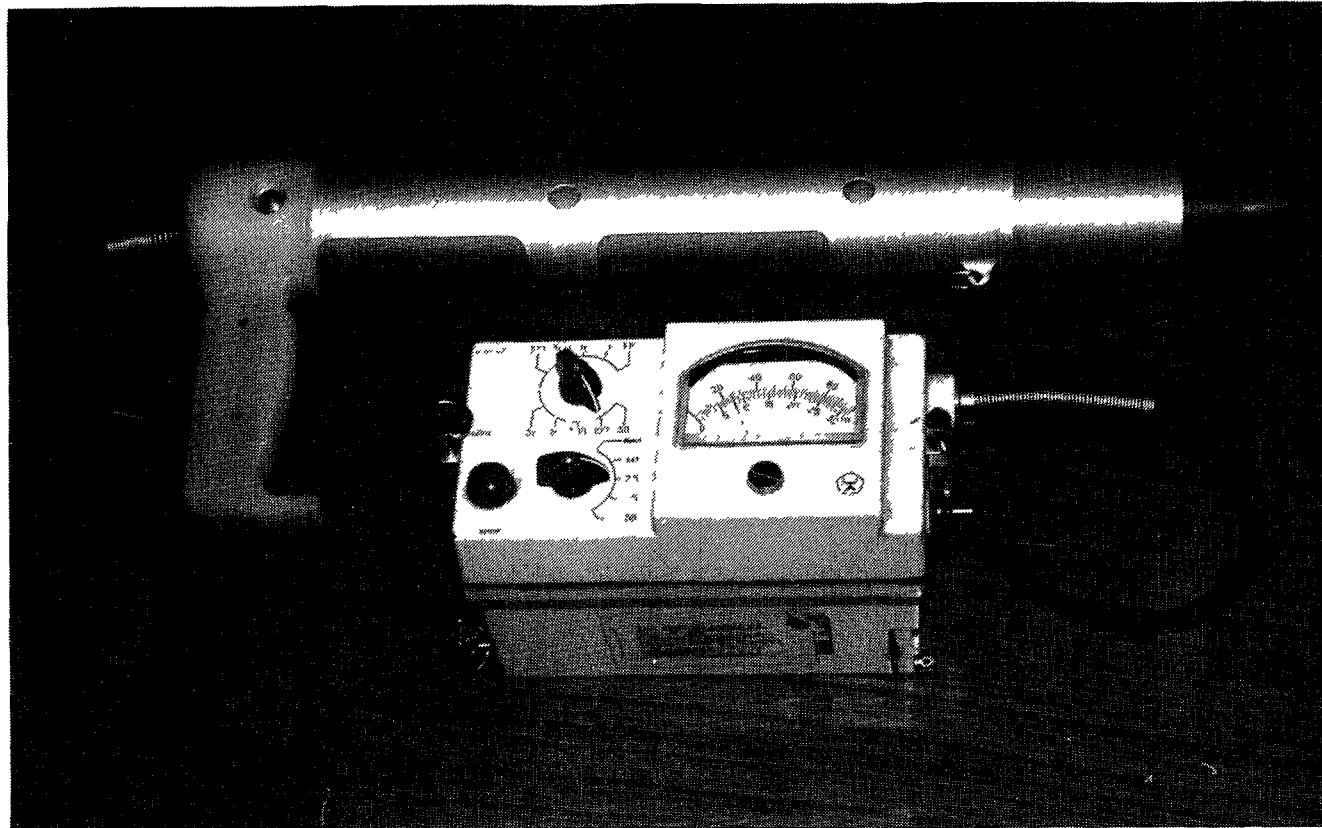


FIG. I-3. Gamma dosimeter SRP-68-01.

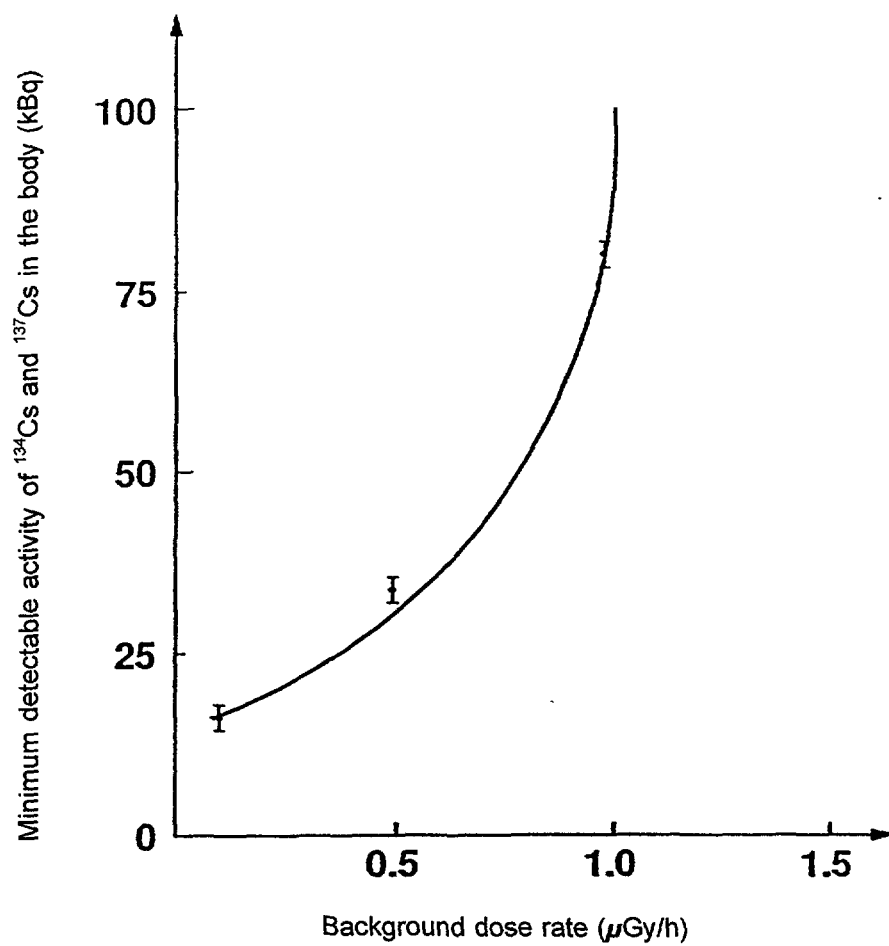


FIG. I-4. Dependence of minimum detectable activity (^{134}Cs , ^{137}Cs) on the background dose rate.

- [I-3] DOLGIREV, E.I., et al., Temporary Methodical Instructions on Express Determination of Caesium-134 and Caesium-137 in the Body of Man, Ministry of Public Health of the USSR, Moscow (1987) (in Russian).
- [I-4] GUSEV, I.A., et al., "Monitoring of internal exposure of the population in regions close to the Chernobyl nuclear power plant", Medical Aspects of the Chernobyl Accident (Proc. Conf. Kiev, 11–13 May 1988), IAEA-TECDOC-516, Vienna (1989) 195–201.

Annex II

MONITORING PROCEDURES AFTER THE RADIOLOGICAL ACCIDENT AT GOIÂNIA, BRAZIL

(This annex has been compiled from material provided by C.A. Nogueira de Oliveira.)

II-1. INTRODUCTION

The accident in Goiânia, Brazil, in 1987 involved the unauthorized removal and subsequent rupture of a sealed teletherapy source containing 51 TBq ^{137}Cs which had been left unsecured in a derelict building formerly used as a private clinic. Much of the material was deposited at a series of sites over about 1 km² in a densely populated region. A total of 118 000 people were screened for internal and surface contamination. Of these, 143 were identified as internally contaminated, following intakes subsequently assessed as up to 1 GBq. In 46 cases decorporation therapy was considered necessary. Four people died as a result of their internal and external exposure and 28 sustained radiation burns. A comprehensive account of the accident was issued by the IAEA [II-1].

II-2. INITIAL SCREENING

Initial screening was performed in Goiânia, at the Olympic Stadium, about 200 m from the nearest site of major surface contamination. The programme started within 24 hours once the seriousness of the situation had been recognized and continued for two months, during which some 118 000 individuals were monitored. For these purposes portable gamma survey meters were used, each consisting of a NaI(Tl) scintillation detector, 38 mm dia. \times 25 mm thick. For ^{137}Cs an indicated 5000 counts/s corresponded to 10 $\mu\text{Gy/h}$. Initially, when the recorded dose rate close to the body was more than 0.8 $\mu\text{Gy/h}$ above the background of 1.2 $\mu\text{Gy/h}$, the subject was referred for more rigorous assessment [II-3]. After several weeks, when decontamination of the environs had reduced the local background to 0.4 $\mu\text{Gy/h}$, the referral criterion was modified to 0.4 $\mu\text{Gy/h}$ above this reduced background.

II-3. RIGOROUS ASSESSMENT OF WHOLE BODY CONTAMINATION

Accurate assessment of internally deposited ^{137}Cs was required in the 143 individuals identified as contaminated in the initial screening programme, and also in workers engaged in the decontamination operations. Additional measurements were made in certain other members of the public, potentially at risk. Where appropriate, serial investigations were undertaken to determine the rate of clearance.

During the first month, assessments were made entirely through measurements of urinary and faecal excretion [II-2]. More than 4000 samples were collected from the 80 patients detained in hospitals in Goiânia itself and in Rio de Janeiro. The ^{137}Cs content of these samples was assessed in Rio de Janeiro by scintillation spectrometry. An improvised whole body counter, capable of functioning at the high levels of contamination found in some of the subjects [II-3] became operational in the Goiânia General Hospital after four weeks. It consisted of a NaI(Tl) detector, 200 mm dia. \times 100 mm, supported 2.05 m above the floor of a room 4.0 \times 3.5 \times 3.5 m³ (Fig. II-1). The detector was provided with a close fitting annular lead shield 50 mm thick. Subjects were required to change into disposable clothing and were accommodated in a reclining fibreglass chair (Fig. II-1) positioned on a

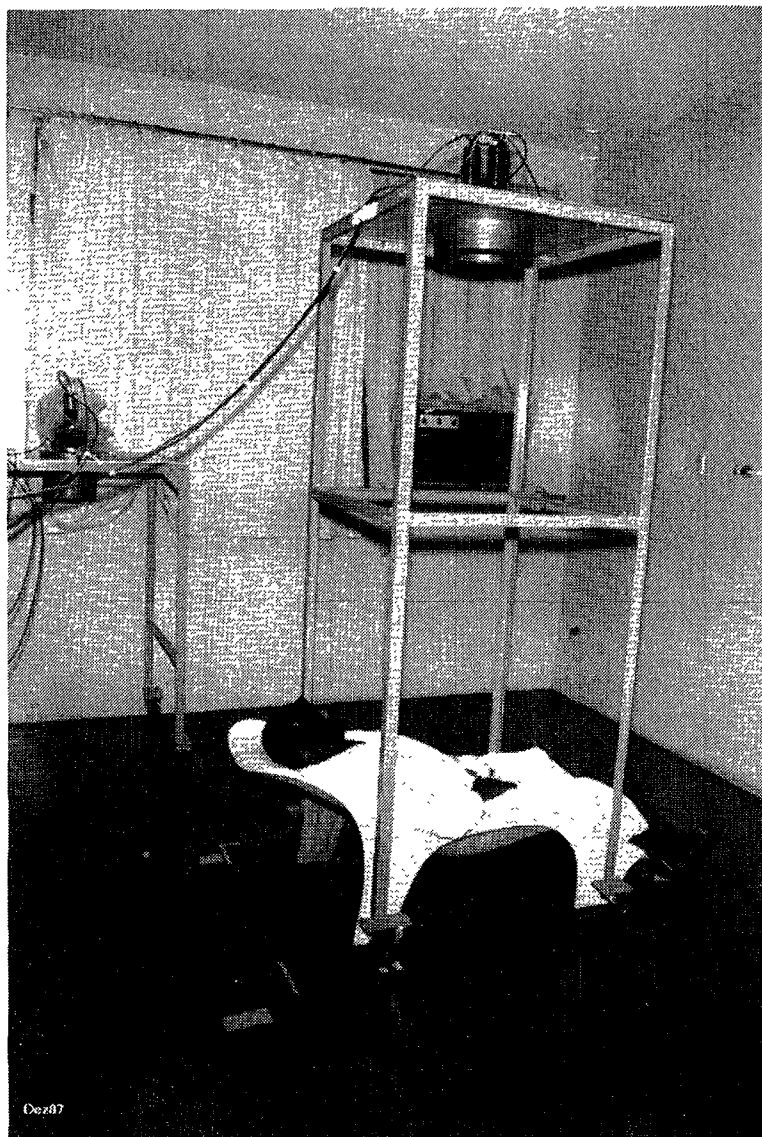


FIG. II-1. The whole body counter improvised in Goiânia.

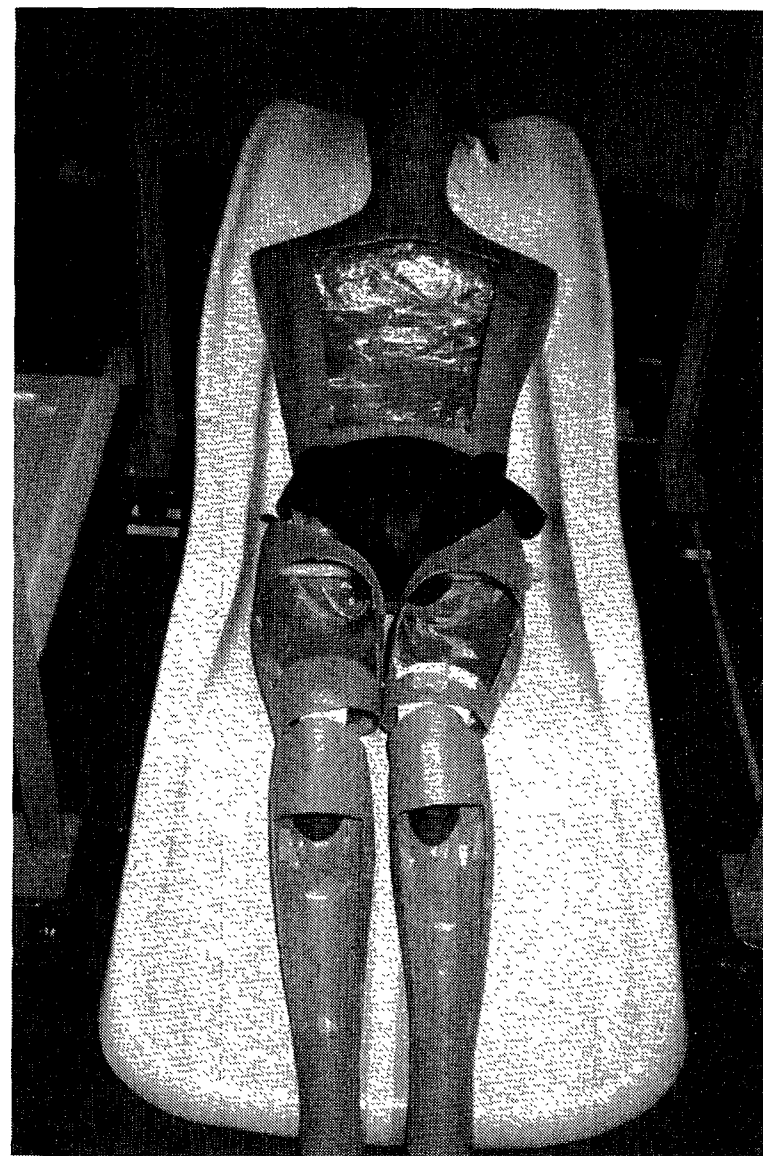


FIG. II-2. An adult sized phantom.

raft of lead 14 mm thick. A standard 2 min live counting time gave a minimum detectable activity (95% confidence) of 9 kBq. Calibration for all subjects, regardless of size, was by reference to the response from a standardized solution of ^{137}Cs dispersed in a commercially available hollow fibreglass mannequin (Fig. II-2) [II-3].

A total of 587 people were referred for investigation in the first six months of operation. Measured activities ranged from below detection limits to 74 MBq. After each initial assessment, a programme of follow-up measurements for each contamination subject was organized, the frequency depending on the level of contamination and on the regime of decorporation therapy adopted in some cases.

REFERENCES TO ANNEX II

- [II-1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).
- [II-2] LIPSZTEIN, J.L., et al., Application of in vitro bioassay for ^{137}Cs during the emergency phase of the Goiânia accident, *Health Physics* **60** (1991) 43–49.
- [II-3] NOGUEIRA DE OLIVEIRA, C.A.N., et al., Design and operation of a whole-body monitoring system for the Goiânia radiation accident, *Health Physics* **60** (1991) 51–55.

CONTRIBUTORS TO DRAFTING AND REVIEW

Andrasi, A.	Central Research Institute for Physics, Hungary
Bucina, I.	National Institute of Public Health, Czech Republic
Colard, J.	Section Nuclear Spectrometry, Mol, Belgium
Doerfel, H.	Kernforschungszentrum Karlsruhe, Germany
Etherington, E.	National Radiological Protection Board, United Kingdom
Falk, R.	Swedish Radiation Protection Institute, Sweden
Gusev, I.A.	Institute of Biophysics, Ministry of Public Health, Russian Federation
Kramer, G.H.	Bureau of Radiation and Medical Devices, Canada
Malatova, I.	National Institute of Public Health, Czech Republic
Moiseev, A.A.	International Atomic Energy Agency
Newton, D.	AEA Environment & Energy, Harwell Laboratory, United Kingdom
Nogueira de Oliveira, C.A.	Institute for Radioprotection and Dosimetry, CNEN, Brazil
Pilar, G.J.	Ontario Hydro, Health Physics Services, Canada
Rahola, T.	Finnish Centre for Radiation and Nuclear Safety, Finland
Ricks, R.	Oak Ridge Associated Universities, United States of America
Righetti, M.	National Atomic Energy Commission, Argentina
Steger, F.	Oesterreichisches Forschungszentrum, Seibersdorf, Austria
Tsvetkova, O.	All Union Scientific Center of Radiation Medicine, Ukraine
Vladar, M.	Research Institute of Preventive Medicine, Slovakia
Werner, E.	Gesellschaft für Strahlen und Umweltforschung, Germany

Technical Committee Meeting

Vienna, Austria: 23–27 January 1989

Consultants Meetings

Vienna, Austria: 11–15 December 1989, 23–27 September 1991