IAEA-TECDOC-1131

Restoration of environments affected by residues from radiological accidents: Approaches to decision making

Proceedings of an International Workshop held in Rio de Janeiro and Goiânia, Brazil, 29 August – 2 September 1994

Jointly organized by the Instituto de Radioproteção e Dosimetria, Comissão Nacional de Energia Nuclear (CNEN) and the Institut für Strahlenschutz, Forschungszentrum für Umwelt und Gesundheit (GSF)

In co-operation with the International Atomic Energy Agency and the European Commission

GSF–Forschungszentrum für Umwelt und Gesundheit

gsf

INTERNATIONAL ATOMIC ENERGY AGENCY

IAEA

May 2000

The IAEA does not normally maintain stocks of reports in this series. They are however collected by the International Nuclear Information System (INIS) as non-conventional literature. Should a document be out of print, a copy on microfiche or in electronic format can be purchased from the INIS Document Delivery Services:

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

Telephone: (43) 1 2600 22880 or 22866
Fax: (43) 1 2600 29882
E-mail: chouse@iaea.org

Orders should be accompanied by prepayment of 100 Austrian Schillings in the form of a cheque or credit card (VISA, Mastercard).

More information on the INIS Document Delivery Services and a list of national document delivery services where these reports can also be ordered can be found on the INIS Web site at http://www.iaea.org/inis/dd_srv.htm.

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides.**

- **Safety Fundamentals** (silver lettering) present basic objectives, concepts and principles of safety and protection in the development and application of atomic energy for peaceful purposes.
- **Safety Requirements** (red lettering) establish the requirements that must be met to ensure safety. These requirements, which are expressed as 'shall' statements, are governed by the objectives and principles presented in the Safety Fundamentals.
- **Safety Guides** (green lettering) recommend actions, conditions or procedures for meeting safety requirements. Recommendations in Safety Guides are expressed as 'should' statements, with the implication that it is necessary to take the measures recommended or equivalent alternative measures to comply with the requirements.

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA.

OTHER SAFETY RELATED PUBLICATIONS

Under the terms of Articles III and VIII.C of its Statute, the IAEA makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its members for this purpose.

Reports on safety and protection in nuclear activities are issued in other series, in particular the **IAEA Safety Reports Series**, as informational publications. Safety Reports may describe good practices and give practical examples and detailed methods that can be used to meet safety requirements. They do not establish requirements or make recommendations.

Other IAEA series that include safety related sales publications are the **Technical Reports Series,** the **Radiological Assessment Reports Series** and the **INSAG Series**. The IAEA also issues reports on radiological accidents and other special sales publications. Unpriced safety related publications are issued in the **TECDOC Series**, the **Provisional Safety Standards Series**, the **Training Course Series,** the **IAEA Services Series** and the **Computer Manual Series**, and as **Practical Radiation Safety and Protection Manuals**.

The originating Section of this publication in the IAEA was:

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

RESTORATION OF ENVIRONMENTS AFFECTED BY RESIDUES FROM RADIOLOGICAL ACCIDENTS: APPROACHES TO DECISION MAKING
IAEA, VIENNA, 2000
IAEA-TECDOC-1131
ISSN 1011-4289

Printed by the IAEA in Austria
May 2000

FOREWORD

The International Atomic Energy Agency, jointly with the Instituto de Radioproteção e Dosimetria of the Comissão Nacional de Energia Nuclear (CNEN), Brazil, the Forschungszentrum für Umwelt und Gesundheit, Institut für Strahlenschutz, Germany, and with the collaboration of the European Commission, held a workshop in Rio de Janeiro and Goiânia, Brazil, in August 1994, on the scientific basis for decision-making after radioactive contamination of an urban environment. This volume presents the proceedings of the workshop.

Eighty-eight participants from 18 Member States and 39 organizations attended the workshop. The main thrust of the workshop was to foster information exchange on the scientific basis for intervention in a *de facto* situation created by an accident affecting an urban area and resulting in long term human radiation exposure.

The venue of the workshop was particularly appropriate. Some years before, in September 1987, an accident involving a lost radioactive source had occurred in the city of Goiânia, causing serious contamination and serious injuries and deaths among members of the public. The IAEA, in close collaboration with the Brazilian authorities and with the help of an international group of senior experts, drew up and published a comprehensive appraisal of that accident so that Member States might benefit from the lessons to be learned. In 1994, seven years after that fateful event, it was felt that the time was ripe to draw further lessons and to facilitate an exchange of ideas among experts.

The IAEA is grateful to all the experts who participated in the workshop and in particular to E.C.S. Amaral, Director of the Instituto de Radioproteção e Dosimetria, Brazil, to H.G. Paretzke, Forschungszentrum für Umwelt und Gesundheit, Institut für Strahlenschutz, Germany, to the Financiadora de Estudos e Projetos (FINEP), Rio de Janeiro, to the Conselho Nacional de Desenvolvimento Cientifico e Tecnológico (CNPq), Brasilia and to the Viação Moreira, Goiânia.

The IAEA officer responsible for this publication was A. González of the Division of Radiation and Waste Safety.

CONTENTS

SUMMARY

This meeting gathered and summarized recent information and strategies on emergency planning and decision making by involving radiation protection scientists, medical doctors and decision makers. The main goal of the workshop was to discuss scientific data as a basis for post accidental (emergency) planning in an urban environment taking into account the experience obtained during the Goiânia and Chernobyl accidents. In general it was emphasized that there is a need for:

- clear intervention limits and internationally accepted values for appropriate levels of radiation protection, in order to avoid confusion;
- well tested and proofed infrastructure and methodologies for measurements, dose assessments and decontamination actions, mobile devices for terrestrial and aerial survey, and transportable in vivo measurement laboratories;
- a handbook showing an optimized strategy for the management of an accidental urban contamination made available by international organizations since it has been shown that the ALARA principle is avoided owing to social and political pressures;
- proper management plans in order to be prepared for medical emergencies arising from exposure to radiation. A medical response based on a three level hospital system showed to be important in dealing with the medical consequences of the accident;
- an integrated response to an accident involving different organizations (such as health, agriculture, environment) at the federal, state and municipal levels in order to make decisions based on the most reliable data available;
- general co-ordination entity for exchange of information among all organizations involved;
- an adequate infrastructure for informing the public and the media, which needs to be linked with all organizations involved.

ENVIRONMENTAL ASPECTS

The complexity of urban surfaces and the diversity of primary and secondary contamination conditions was pointed out. Therefore, although surveys at the sheet level and by air were considered adequate for the identification of the main contamination areas, additional knowledge was gained regarding the optimization of the adoption of decontamination procedures:

- it is fundamental to conduct indoor and environmental measurements to obtain information on the type of contamination to better understand the processes involved in the behaviour of radionuclides;
- it was suggested to standardize methodologies, and as a consequence predictions should be made based on deposition on smooth surfaces (e.g. soil, grass);
- the amount of waste generated and late management of waste has to be taken into account. For example, the PARATI model developed after the Goiânia accident has an archive to compute the amount of waste generated per m^2 of contaminated area/surface;
- the surface soil and local resuspension processes have shown to be relevant radiation sources, which contribute to the contamination of local indoor and outdoor urban surfaces as well as the contamination of small animals kept locally such as chickens etc.;
- regarding the internal exposure of the urban population, the identification of critical groups was shown to be highly dependent on consumption habits and the local food distribution system.

After the initial screening with portable detectors of potentially contaminated persons and the identification of affected people, there is a need for (a) external decontamination, and (b) selection of individuals internally contaminated for further treatment. These procedures are strongly influenced by the available infrastructure and individual emotional conditions. The following conclusions were drawn in this connection:

- skin decontamination should be performed at hospitals by physicians together with radiation protection staff. The need for well trained physicians to deal with emotionally stressed people was pointed out;
- the importance of implementing in vivo measurement laboratories to be used mainly in emergency situations was stressed in order to identify internally contaminated individuals. In Goiânia, urine and faeces were analysed for ^{137}Cs contamination to evaluate internal contamination and the elimination efficiency of Prussian Blue. The reason for this procedure was the distance between Goiânia and any radiation protection centre with the capability to perform in vivo measurements, and also because most of those individuals also had external contamination;
- a novel contamination detection system which had been developed and implemented in Goiânia was presented. It consisted of a multiple geometry system with vertical and horizontal movements of detectors allowing to measure either children or adults, and high and low activities;
- the analysis of uncertainties and minimum detectable activities in enhanced background levels has justified the use of high resolution gamma spectrometry for the measurement of internal contamination in emergency situation. The INDOS detector system developed at the Karlsruhe Research Center can be installed as a mobile unit in a container for transportation by car, train or aircraft, and its results are available after a very short measuring time (20 s). This system allows measurement of all subjects with body heights ranging from 150 cm up to 200 cm. However, it is not appropriate for measurements on children;
- Prussian Blue (PB) in doses of 3–6 or 10 g/d for adults and 1 and 3 g/d for children was used to enhance the elimination of ^{137}Cs from the body of people internally contaminated in Goiânia, and has shown to be quite effective. When PB is administered after the influence of the first term retention has ended, its effectiveness on Cs decorporation has shown to be independent of age and dosage. The reduction factor depends on the time at which the drug is administered the committed dose was reduced by a factor of 1.7 to 3.4 for children and adolescents, and from 2.1 to 6.3 for adults;
- a caesium retention model was developed based on the Goiânia data consisting of three exponential terms. The first retention fraction is a function of body weight (negative correlation); the second term is a biological half-time reflecting the progressive loss in urine and faeces as a function of body weight until adulthood is reached. Concerning adults, a significant difference in gender was found without any correlation with age and weight. The caesium transfer factor from mother to foetus is dependent on its availability in the blood;
- the comparison between internal committed absorbed dose and the dose estimated by cytogenetic techniques demonstrates the importance of discriminating between internal and external radiation exposure of persons;
- the follow-up of the Goiânia patients suggested that the rate of unstable chromosome aberrations is dependent on the dose received by the individual studied. This would explain discrepancies between determined half-times for the disappearance of unstable

aberrations published by different authors. The FISH technique to detect stable aberrations after high radiation exposures was shown to work appropriately.

MEDICAL ASPECTS

In Goiânia individuals were exposed to external irradiation, but also had heavy skin exposures and internal contamination. Therefore Prussian Blue for decorporation of radiocaesium was used to a large extent. The use of recombinant human granulocyte macrophage colony stimulating factor (GM–CSF) and the implementation of bone marrow transplant (BMT) regimen was also discussed. From the discussions the following conclusions were drawn:

- Prussian Blue has a high effectiveness in decorporation of caesium in humans;
- GM–CSF was for the first time used for humans exposed in the Goiânia accident, however because of its use at a later stage of bone marrow depression, no conclusions about its effectiveness are allowed;
- the experience obtained from other accidents has shown that the most urgent questions are the eligibility for BMT, whether an accident victim will benefit from BMT, and by which degree lethality will increase when a patient is submitted to a BMT regimen;
- the intensification of research in establishing a proper diagnosis of acute radiation syndrome as early as possible in order to decide on the benefits of supportive treatment, haemopoietic growth factors and BMT.

OPENING ADDRESS

J. Klein
National Center for Environmental and Health Research,
Germany

Presented by U. Deffner

You might be curious and interested to know why this workshop has been organised jointly by two scientific organizations, namely IRD and GSF, which are located about 10 000 km apart.

The co-operation of both institutions has a long tradition reaching back more than twenty years.

GSF was founded in 1960 as a "Higher Education and Training Facility for Radiological Protection Sciences" by the Nuclear Research Centre, Karlsruhe, at Neuherberg near Munich. Since then, the lab has grown in size to about 1700 employees and in thematic width to include a total of 21 institutes dealing with many different aspects of general environmental and health related research. Today only our "historic" abbreviation "GSF", i.e. "Gesellschaft für Strahlenforschung–Laboratory for Radiation Research" reminds you of our origin.

However, the initial mission of teaching and training in radiation protection is still alive and strongly followed in the original founding institute of GSF, the ISS.

In this spirit of teaching and training, Dr. Günter Drexler from GSF was sent by the International Atomic Energy Agency in Vienna, even before the foundation of IRD, in 1972 as an expert to the CNEN Laboratório de Dosimetria. This laboratório was headed by Dr. Rex and installed at PUC.

Dr. Drexler then helped him in setting up clinical dosimetry in Brazil. This effort had as a final result e.g. the nomination of IRD as a member of the WHO/IAEA Network of Secondary Standard Laboratories — nowadays it is the Brazilian Legal Metrology Laboratory for Ionising Radiation.

Then the "Bilateral German–Brazilian Agreement on Nuclear Co-operation", signed in 1975, has also an impact on the scientific co-operation of IRD with GSF. This was mainly in the areas of Radiation Metrology, Occupational Radiation Protection and Medical Physics.

Here it is also appropriate to mention the "silent" contributions of the first director of the "GSF–Institut für Strahlenschutz", Prof. Dr. med. Rudolf Wittenzellner, who became later the first director of the whole GSF, who fully supported these activities and who underlined at several occasions the spirit of the co-operation between GSF and IRD:

The up grading of the infrastructure in the medical use of ionising radiation, especially in X-ray diagnostics, with the help of GSF in the framework of an IAEA "Footnote a" project, financed by Germany, had a large impact not only in Brazil but shows also positive signs in the entire Latin America.

Dr. Drexler is still teaching and training here as an expert in this field, as e.g. two weeks ago in a large course on this topic, organised by IRD on behalf of the IAEA.

It was also him who was the first non-Brazilian providing urgently needed help after the Goiânia accident:

When Dr. Rex, then the President of CNEN, called him on a Friday late a afternoon, i.e. within hours after he himself learned about this accident, he succeeded in finding some supply of the radioprotector "Radiogardase" in Germany and in organising its transport so promptly, that it could be applied already on Saturday afternoon by the medical doctors to the victims in Brazil.

Further support by sending dose rate meters and contamination monitors from GSF followed only little later. Also due to his efforts the first blood samples of victims were analysed for chromosome aberration by Prof. Bauchinger at GSF to provide first estimates from biological dosimetry.

Later on, when the acute clean up period in Goiânia was over, time permitted to consider also scientific projects following up the fate of the initial contamination of this city.

Then, since 1988, another co-worker of GSF, namely Dr. Herwig Paretzke, now the fourth director of our Institut für Strahlenschutz, came to IRD and Goiânia on numerous missions as an IAEA expert for teaching and training in the field of radioecology and risk assessment and in the framework of a CEC research project.

He helped to develop at IRD the capability for environmental modelling and risk assessment. The influence of his work at IRD can be seen e.g. in several presentations given at this workshop, in a MSc thesis and in numerous common publications with his colleagues of IRD. He served as an advisor for the PhD work of Elaine Rochedo developing a predictive exposure model for the urban environment, who successfully passed her final university examinations just a few days ago ("congratulation also from us"). He was also the scientific PhD-advisor for the most important member in the Organising Committee of this workshop, namely Dr. Eliana Amaral, in her work on the dose assessment in the high natural background area of Pocos de Caldos, who became now the new director of IRD just two months ago.

LESSONS FROM GOIÂNIA

R. NAZARI ALVES
Instituto Militar de Engenharia,
Rio de Janeiro, Brazil

Abstract

LESSONS FROM GOIÂNIA.

The lessons learned from the radiological accident of Goiânia in 1987 derived from the observations from the Regulatory Agency which was in charge of the decontamination tasks may be consolidated into four classes: *Preventive Actions,* characterised as those that aim to minimise the probability of occurrence of a radiological accident; *Minimisation of time between the moment of the accident occurrence and the beginning of intervention,* in case a radiological accident does occur, despite all preventive measures; *Intervention,* which is correlated to the type of installation, its geographical location, the social classes involved and their contamination vectors; and *Follow up,* for which well established rules to allow continuing monitoring of the victims and rebuilding of homes are necessary.

The greatest lesson of all was the need for integration of the professionals involved, from all organizations.

1. INTRODUCTION

The lessons learned from any event in which a person has participated depends on his position during its occurrence. In the specific case of the radiological accident of Goiânia, in 1987, the lessons shown here are derived from the observations from the Regulatory Agency responsible for the production and commerce of nuclear materials and radioactive sources which was also in charge of the decontamination tasks. Seven years after the accident four classes of learning have been consolidated: prevention; minimising time between the moment of the accident and the beginning of action; intervention and follow-up.

2. PREVENTIVE ACTIONS

Preventive actions have been characterised as those that aim to minimise the probability of occurrence of a radiological accident. This minimisation is influenced by the control and responsibilities pyramid, the frequency and types of control, the audit of these controls and the difficulties found in this procedure. The control and responsibilities pyramid include the participation of the operator, the NATIONAL NUCLEAR ENERGY COMMISSION, MILITARY INSTITUTE OF ENGINEERING, governmental organizations from the City, State and Country. Since the operator is the only one with permanent control on the installation he should bear the main responsibility. As a consequence, he should have technical abilities that allow him to understand all the aspects involved in this responsibility. By analogy, it is supposed sharing of responsibility between a vehicle driver and the government agency that verifies the ability of the driver and the mechanical and safety conditions of the vehicle. It is also supposed that at some time this subject will either suffer of cause an accident. In case the accident was caused by a negligent driver, lack of proper maintenance of the brakes for instance, only this driver could have avoided the accident, never any other organization involved in issuing a drivers license or vehicle registration documents. This fact, however, does not omit the action of governmental organizations to establish rules, frequency and types of controls, to minimise the possible accident consequences. In the specific case of radioactive sources operation, the frequency of control of existing sources should be daily, by the operator. The integrity verification should be periodical. It should be emphasised that this operator routine check becomes boring reducing its reliability. A weekly report to the regulatory agency could improve credibility of the quantitative information. To this government control it could be added quality controls, both of integrity and of optimisation of operational procedures, with results in visual qualification of the installation to the general public. What happens is that these preventive actions, specially in Developing Countries, are difficult to implement by conflicts between legal aspects and necessary technical actions. Also a lack of qualified professionals, geographical dimensions and the growing use of radioactive sources, contribute to make preventive actions a difficult task. It should be remembered that social problems in Developing Countries, some very urgent, conflict with the necessary safety actions. These difficulties are even greater since one verifies that the technical skills of operators are mainly located in the Hospital Network, in the Nuclear Medicine and Radiotherapy sectors. On the other hand a large number of government agencies, particularly in small cities lack technically qualified personnel to implement the legal controls. It should be emphasised that in many countries as well as in Brazil the medical use of radioactive sources started more than a decade before a system to control their use and to assess the risks involved. Even today the use of radioactive sources in smoke detectors places a new risk to non qualified maintenance personnel, although these risks are small and localised. At the same time the law is slower to change to keep up with the fast evolution of radioactive source applications.

3. MINIMIZATION OF TIME BETWEEN THE MOMENT OF THE ACCIDENT OCCURRENCE AND THE BEGINNING OF INTERVENTION

If, despite all preventing measures, a radiological accident occurs, the affected area, the number of victims and the psycho-social effects will be influenced by the time between accident initiation and the identification and intervention. It is natural that factors that influence in these times reduction are correlated with those of the preventive actions. Thus, the type and frequency of control constitute the first accident indicators. It is required that the established control system be preserved reliably and ready to actuate.

However, as in the case of ophthalmologic sources, not always this conscientization of the risks involved exist among operators becoming necessary the employment of other local indicators of popular use. It is considered that these indicators can be utilised from a chain in which, for instance, radioprotection supervisors, medical doctors, pharmaceuticals and fire men participate.

In the case of material robbery, another agent is necessary, the receptor, lying in line between the legal and the illegal. These receptors are not reliable information sources and normally become national distribution vectors, since the stolen objects are not negotiated in the region where the robbery occurred.

4. INTERVENTIONS

Although it is possible to determine some accident scenarios, these will never include all aspects involved in intervention. The type of installation, its geographical location, the social classes involved and their contamination vectors are all correlated.

Thus, some basic principles of practical origin, extracted from the decontamination of Goiânia experience will be related.

— Intervention Levels:

The ICRP 26 and 60 predict that the radioprotection actions should be based in limits as low as reasonably achievable, considering economic and social aspects.

After the start of the intervention at some site the local public, by natural curiosity, becomes the main controlling agent, practically demanding that the exposure levels return to the original values. In this way record and intervention levels defined in the Radioprotection Basic Standards become only reference values.

In Goiânia the return of the exposure levels to their original values resulted in an excessive amount of waste compared to what should be removed to prevent radiological risks.

The lack of conceptual knowledge in which intervention levels are based, contributes to discrimination of sites, people and products. This discrimination can be reduced by the action of people involved in decontamination. The credibility in this action of the technical team has aspects pureed personal and its use in the wrong fashion can work in the opposite direction producing more discrimination. It is natural that the actions are taken considering the local characteristics. In Goiânia, the public living near the contaminated areas, offered water, juices, coffee and local fruits to CNEN technicians trying to identify rejections indicating possible contamination.

— Co-ordination and Unified Action:

Although government agencies planning for intervention should exist, some characteristics should be anticipated and legally consolidated to reduce and enable intervention.

The lack of previous knowledge of the area involved in the accident, the number of victims, the contaminating material, the site characteristics, makes impossible to a single agency to possess all necessary means to intervention. It is a must the participation of several organizations with well differentiated subordination demanding a co-ordination including federal, state and city agencies and an unified command.

This unified command should have legal authority to all necessary actions. Additionally, to existing global planning daily procedure should be proposed resulting from the work development. This unified command should remain in the area during all process of intervention.

— Legal Aspects:

Intervention characterises an emergency demanding urgent decision. These include exceptional procedures on material acquisition, importing, hiring of services and material disposal. Customs barriers should be removed to import medical products, equipments and consuming materials. On the other hand it should grant the authority to isolate areas, retrieval of contaminated goods, decontamination or demolishing of houses, selection of areas to store temporary waste and co-ordination to victim support.
The lack of these exceptional legal tools, can prevent or delay an effective action disabling the minimising of intervention time.

— Waste Area:

The beginning of decontamination of the affected area produces a large amount of waste that should be immediately removed. The choice of a region nearby for temporary storage is a must. This area should possess characteristics that allow it in the future to become a permanent waste site. This avoids transport accidents and unnecessary personnel exposure.

— Local Products Verification:

The social phenomena of discrimination occurs not only near the affected area but also in faraway regions.

During the Goiânia accident it was normal discrimination against vehicles with Goiânia license plates.

Additionally, non ethical financial interests led to discrimination of Goiânia region products, as well as from faraway points not affected. It is important the creation of groups to analyse the products, issuing certificates to avoid this discrimination reducing the psycho-social impact of the accident. The analysis results should have legal backup and should be final.

— Personal Damages:

The victims classification, the sites and rescue teams should be immediately defined. It was observed that in the preparation of medical teams to look after the Goiânia victims there were no nurse paramedicals and cleaning personnel with enough background in radiological protection.
Additional problems were lack of laboratory support to perform clinical analysis, laundry, collection and disposal of hospital and decontamination wastes and medical equipment.

FOLLOW-UP

The insufficiency of funds in developing countries makes necessary establishing priorities to future actions once the cause has stopped. It is adequate to existence of well established rules to allow continuing monitoring of the victims, rebuilding of homes, indentations. These needs should be based on proper laws.

CONCLUSIONS

Despite without all conditions previously established, the rapid decontamination of the affected area and the victim assistance, presented positive reports by specialists and international organizations. This is attributed to the solidarity of the different federal, state and city agencies supported by technical ability of the Comissão Nacional de Energia Nuclear staff.
A great lesson was the integration of all the professionals involved, from all organizations, becoming an example of efficiency in short time.

CHALLENGES TO DECISION MAKERS AFTER URBAN CONTAMINATION: THE CHERNOBYL EXPERIENCE

I. LIKHTAREV
Scientific Center for Radiation Medicine,
Kiev, Ukraine

L. ILYIN
Institute of Biophysics,
Moscow, Russian Federation

Abstract

CHALLENGES TO DECISION MAKERS AFTER URBAN CONTAMINATION: THE CHERNOBYL EXPERIENCE.

The real history of the Chernobyl decisions will probably be published in ten or fifty years after the death of the politicians who made those decisions and the soviet scientists who were there creating them. But that is not out of the possibility that real and tragic history will never be published at all.

This is mainly because the most hard and responsible Chernobyl decisions which had to be made in the situation of acute time, skill and information deficit, had been marked by the stamp of time and society where all of us, including the authors, were living.

Never before, and I hope very much, never in the future, has humanity faced the industrial nuclear-radiation accident with the scale like Chernobyl NPP accident. So it's extremely important to summarise and put together not only the scientific but human experience of the scientists which directly formed the large-scale decisions. It is very important to explain to society not only the scientific background of those decisions but also the scientists' personal views, their personal impressions as at the time of decision making as in eight years after the accident.

1. THE RESPONSIBLE AUTHORITIES AT THE EARLY STAGE OF THE CHERNOBYL ACCIDENT

The leaders of the former Soviet Union took the main roles in the management and in the work of the main Chernobyl State-Government Commission. The administrative authorities of Ukraine and Belarus had been informed about the decisions of the Main Commission and carried out the executive functions. Certainly, the Republic and Regional Accidental Commissions existed as well, but the role, scale and influence of their decisions were much more smaller because of the doctrine of absolute centralisation of the power which was at that time.

Necessary scientific competence of scientists for the Main Commission had been provided via the Scientific Institutes of the Soviet Union Academy of Science, Health Ministry of Soviet Union, Ministry of Middle Machinery Making, Defence Ministry and, but in less measure, by the Scientific Institutes of Ukraine and Belarus Academy of Science and by the Institutes of the Republic ministers.

2. MAIN GROUPS OF POSTACCIDENTAL DECISIONS

All the important Chernobyl decisions may be divided into two large groups:

First, the decisions dealt directly with the Fourth Accidental Unit, with decontamination and putting into operation the First, Second and Third Units of the Chernobyl NPP and with the working of special contingents in 5–, 10– and 30 kilometre zones around the plant. It is possible to make some independent, very important presentations on the first group of decisions.

The second group of decisions includes the urgent, early-stage and long-term countermeasures for the protection of the population who found themselves on the contaminated territories. Very symbolically this second group of decisions can be divided into two subgroups. There are the countermeasures for protection of rural population and ones of urban inhabitancies.

In accordance with the main topic of our workshop the main attention will focus on the urban decisions which had been made after the Chernobyl accident and on the main experience which was obtained.

3. INTERVENTION LEVELS

A long time before the Chernobyl accident a set of documents where the intervention levels (A and B) at the case of hard nuclear accident had been created in the former Soviet Union. Those levels determined the radiation situation when the evacuation and iodine prophilaxis had to be made [1-3]. Besides, the official instruction of Soviet Union Health Ministry on the accidental situation existed.

In 70-th years the large investigation on the development the optimal dosages, strategy and tactics of using KI for mass pharmacology protection of thyroid gland exposure in the case of large-scale radioiodine contamination had been completed [4]. However, the Chernobyl experience has shown that practical realisation, all even very good, detail and scientific-substantiation recommendations and intervention levels were rather difficult.

4. MAIN PROBLEMS OF USING THE INTERVENTION LEVELS AND OFFICIAL INSTRUCTIONS

Consider the main difficulties which arose during the decision making in urban radioactive contamination with the examples of some important events:

- Evacuation of Pripjat-town
- Iodine prophylactics
- Temporary relocation
- First May Demonstration in Kiev

4.1. Evacuation of Pripjat

According to the accidental criterion the evacuation may be done if the exposure exceeds 0.25 Sv. Evacuation must be done obviously if the exposure exceeds 0.75 Sv. Already on 26 April the Governmental Commission accepted the decision on the evacuation of Pripjat-town, although the real exposure hadn't exceeded even 10 percentiles of level A. So it seems, that decision was accepted in opposition of the formal recommendations.

The final decision on the evacuation of Pripjat had been accepted at noon on 26 April 1986 taking into account the recommendations of the physicists. Mainly the arguments were:

- very clear understanding that the radioactive release from the 4th Unit was continuing and no possibility for stopping the release existed in the nearest time;
- comparison of the meteorological situation with the speed of the worsening of radiation gave one evidence that there was the high possibility of the sharp worsening of the radiation situation in any nearest hour and day;

- Pripjat-town located very close (about 3 km) to the 4th accidental Unit where the gamma-exposure rate was enormously high ("red wood", building place of 5th Unit and other).

Here it is very important to stress that such, in principle, very logical reasons for the decision on the evacuation were never maintained before neither in Soviet nor in international documents.

The authors believe that the recommendations for using the levels A and B for the decision on the evacuation have to be accompanied by the very strict commentaries and explanations on their application. Such types of commentaries should include:

- the time-interval during which these levels should be reached (for instance 1-4, 10 or 100 days);
- the part (percentile) of population which has to be exposed above the intervention level;
- the most critical points (moments) of scenario of accident according to when the levels A and B may be exceeded;
- main requirements to the radioecological and dosimetric information (there structure and volume) which can more reliably provide the prediction of an accidental situation.

Naturally, the additional terms have to be formalised in the framework of some software for decision making support. Such a system has to be a powerful tool in the hands of experts analysing the accidental scenario.

A prototype of such a system is now being developed by some European Institutes financed by the CEC.

But in April of 1986 no such things existed and the actual decision on the evacuation had been taken based on the expert estimations.

4.2. Iodine prophylactics

In accordance with the accepted intervention levels the actions on the protection of the population in the case of a radioiodine attack may be introduced when the thyroid exposure exceeds 0.25-0.3 Gy (level A) and, must be absolutely introduced if exposure 2.5 Gy (level B) is reached or exceeded.

Whole series of additional limitations on the feeding and behaviour may be introduced besides the iodine prophylactics. But it has to be stressed that scientists recommended to the Central Governmental Commission to introduce this action on 30 April. The Commission discussed this proposition for 20 days, but officially the decision on the iodine prophylactics had never been accepted. A common position on the necessity of introducing the iodine prophylactics in the Governmental Commission of Soviet Union Health Ministry was absent.

But putting aside the problem of opinions and positions we'll go back to the so-called scientific and technological aspects of decision making.

Two important, from our point of view, moments have to be noted concerning both the mass iodine prophylactics and the levels of starting the interventions:

Application just dose intervention levels for thyroid gland needs, at least, three additional explanation terms:

- whether these levels deal with the exposure of some age-weighted population or with some percentile of people from one age-subgroup;
- probably these levels may be considered as more conservative or as maximum possible thyroid exposure under most conservative assumptions. In that case we have to agree that all real doses will be much less than these conservative predictions;

- the very definite rules and proceedings for the control of decreasing of real doses at the case of introducing the restriction actions have to be created.

If the decision on the iodine prophylactics is made, the effectiveness of this countermeasure is very dependent on the providing level of its realisation. It includes:

- the creation of system of mobilisation reserve of KI in the scale of stage, areas, oblast, rayon;
- system of fast notification of population and organizations providing the distribution of KI;
- system of control of number of involved people and quality of prophylactics.

Here we can stress that direct calculations of the amount of consumed KI at Ukraine during May of 1986 gave the estimation 5 mln/person. But even now it's not clear whether each person from this 5 mln accepted one dosage of KI, or o.5 mln inhabitancies consumed 10 dosages of KI.

4.3. Temporary removal of children and pregnant women

There were no dose or other criterion for intervention levels for such kinds of countermeasure before the Chernobyl accident. A lot of serious debates concerning the introduction of this countermeasure for Kiev took place.

As is well known, before noon on 30 April, because of the meteorology situation the radiation influence of the accident in Kiev was practically absent. But already on 3 May the situation around the decision on possible removal of 0.5mln children became very strong. Dosimetric reasons for such countermeasures were absent.

But some leaders of Ukraine and Kiev and many scientists felt very strong pressure from the public opinion and because of the high registered levels of gamma-exposure rate. From a psychological point this situation was very understandable. It is very easy to understand those rather rich inhabitants of Kiev who did not wait for the official decisions and removed their families and children to other areas of Ukraine and Soviet Union.

As a result of all this the decision of the Ukraine administrative authorities on the mass removal of children for summer health-improving rest for Kiev, Jitomir, Chernigov and other cities had been accepted.

This temporary removal of children and pregnant women which had been taken from 10-12 May of 1986 really averted a significant portion of children from collective thyroid exposure dose and partly from the ingestion doses as well.

The Chernobyl experience has shown that for such a situation a special intervention levels system based on a cost-benefit analysis has to be developed. At this, the advantages from both averted doses and psychological effects must be included in the structure of the "benefit" portion of scales. Some such investigations are now being developed in the framework of one of the Joint Study Projects of the CEC.

This problem falls out of the framework of some common intervention level creations. The matter is that the loss of health inside the Ukraine and Belarus population, as a result of the Chernobyl accident, has to be considered not only as radiation induced illnesses but, follow the WHO-definition, "health is the state of full physical, psychological and social happiness but not only the absence of illnesses".

4.4. May First Demonstration in Kiev at 1986

The first of May was a major holiday in the former Soviet Union. Keeping with tradition a large demonstration took place on that day.

To date sharp debates on the question why the May First demonstration had not been cancelled, why time spent outside especially for children had not been limited in spite of the gamma-exposure rate on 1-2 May which reached peak values (1 and more mR h^{-1}) have been held.

Already in May of 1987 the entire structure and levels of exposure for the inhabitants of Kiev had been estimated. As a result the average external exposure during the 12 month period was about 3.5 mSv and the average internal (without the thyroid exposure) exposure was 1.5 mSv. The portion of cloud exposure in external doses didn't exceed 10%. Exposure obtained during the May First demonstration was not more than 1% of the total annual dose.

Certainly, the cancellation of the May First demonstration could not have provide a significant decrease in total exposure. But on the other hand it seems absolutely unacceptable to have a situation where a hundred thousand people including children walked outside when the gamma-exposure rate from the radioactive depositions was a hundred times higher than the ordinary background.

So a system of operative decisions and intervention levels which takes into account both socio-psychological positive effects following the averted doses and hard diseases from the acquit deformation of a regular style of life (for instance the total panic in a big city) must be developed.

5. CONCLUSIONS

Commentaries on some very important decisions have been left out of this presentation:

These are:

- establish the accidental dose limit for the clean-up workers (liquidators) which were 0.25 Sv in 1986, 0.1 Sv in 1987 and 0.05 Sv later;
- establish the accidental annual dose limit for population on the high contaminated territories: 0.1 Sv for the first year and 0.03 Sv for the second and third years;
- establish the temporal permissible levels for the contamination of water, food and ground;
- establish the values of intervention levels on the dose and ground contamination criterion for permanent relocation (life-time dose, annual dose and others).

All of these decisions were followed not only by long and hard scientific and unscientific debates and discussion but by the human passion as well. Very often since the beginning of the time of "glasnost" the introduction of those decisions was accompanied by the storm of critical publications in mass media.

But to round off the final conclusion on the accident decisions we are absolutely sure that the Chernobyl experience has to be used in two directions.

First, it is necessary to create a powerful computer system of rules and procedures instead of a table of intervention levels.

Second, the decision making system has to include socio-psychological acceptability for both the decisions themselves and their consequences for the population and society which come under the decisions.

Probably this system is only the author's dream, but the progress is important without such dreams.

REFERENCES

[1] Temporary recommendations on the development of the actions on the protection of population at the case of nuclear reactor accident, Moscow (1971) (in Russia).

[2] ILYIN L.A., AVETISOV G.M., Criterion for decision making for the protection of population at accident of reactor, Medicine radiology, (1983), N5, p. 92 (in Russia).

[3] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Protection of the Public in the Event of Major Radiation Accidents: Principles for Planning, ICRP Publication 40, Pergamon Press, Oxford and New York (1984).

[4] ILYIN, L.A., ARCHANGELSAYA, G., KONSTANTINOV, Y., LIKHTAREV, I., Iodine in the radiation safety problems, Atomizdat, Moscow (1972) (in Russia).

TOWARDS AN INTERNATIONAL REGIME ON RADIATION AND NUCLEAR SAFETY

A.J. GONZÁLEZ
International Atomic Energy Agency,
Vienna

Abstract

TOWARDS AN INTERNATIONAL REGIME ON RADIATION AND NUCLEAR SAFETY.

The 1990s have seen the de facto emergence of what might be called an "international regime on nuclear and radiation safety". It may be construed to encompass three key elements: legally binding international undertakings among States; globally agreed international safety standards; and provisions for facilitating the application of those standards.

While nuclear and radiation safety are national responsibilities, governments have long been interested in formulating harmonised approaches to radiation and nuclear safety.

A principal mechanism for achieving harmonisation has been the establishment of internationally agreed safety standards and the promotion of their global application.

The development of nuclear and radiation safety standards is a statutory function of the IAEA, which is unique in the United Nations system. The IAEA Statute expressly authorises the Agency "to establish standards of safety" and "to provide for the application of these standards".

As the following articles and supplement in this edition of the IAEA Bulletin point out, facilitating international conventions; developing safety standards; and providing mechanisms for their application are high priorities for the IAEA.

1. BINDING CONVENTIONS

In recent years, legally binding international conventions have come to play a crucial role in improving nuclear, radiation, and waste safety. They include conventions on early notification and assistance in case of accidents, and the recently adopted conventions on nuclear safety and on spent fuel and waste safety.

The IAEA assists this process by facilitating agreements among Parties and providing a range of functions to the Parties once they agree on the undertakings. These functions include acting as Secretariat to meetings of Contracting Parties, maintaining records of national points of contact, and rendering services to State Parties upon request.

2. SAFETY STANDARDS

By 1998, the IAEA in co-operation with its Member States had developed and issued more than 200 standards of safety in the Agency's Safety Series publications. They cover the fields of nuclear safety and radiation safety, including radioactive waste safety, and radioactive material transport safety.

Dozens of documents in these fields currently are in stages of review, revision, and preparation. They cover safety policies, requirements, and recommendations that are issued under a new hierarchical structure in a new IAEA Safety Standards Series of publications. All of the documents also are developed under a new uniform review and preparation process that has been set up. This process involves five recently established advisory bodies, having harmonised terms of reference and composed of experts appointed by IAEA Member States.

The IAEA safety standards are substantiated by findings on radiation levels and effects estimated by the United Nations Scientific Committee on the Effects of Atomic Radiation. They are primarily based on recommendations of the International Commission on Radiological Protection (ICRP), a non-governmental scientific organization founded in 1928, and the International Nuclear Safety Advisory Group (INSAG), an independent group of experts founded in 1985 which, under IAEA auspices, elaborates nuclear safety principles.

3. APPLYING THE STANDARDS

Regarding the provisions for the application of safety standards, the IAEA has extensive ongoing programs. They include activities for: providing direct safety-related assistance to Member States; fostering the international exchange of safety-related information; promoting education and training in safety areas; rendering a wide range of safety-related services (including radiological assessments) to requesting States; and, co-ordinating safety-related research and development projects.

Technical co-operation activities include a Model Project on "Upgrading Radiation and Waste Safety Infrastructure" involving 52 IAEA Member States. Participating countries are working together with the Agency to address deficiencies and achieve an adequate system for the regulatory control of radiation sources.

Additional activities include an extra-budgetary program on the safety of WWER and RBMK nuclear power plants to enhance assistance to countries of Eastern Europe and the former Soviet Union; and a regional project to improve radiation protection at these same reactors.

The IAEA operates jointly with the OECD Nuclear Energy Agency (NEA) an Incident Reporting System for the exchange of information on safety significant events, and a similar service has been set up covering research reactors. In the area of radiation safety, the IAEA provides a route for non-OECD member countries to take part in an NEA/IAEA Information System on Occupational Exposure. The IAEA also implements more than twenty co-ordinated research projects on particular aspects of nuclear, radiation, and waste safety, and organises at least one major conference each year to foster information exchange in these matters.

But the more challenging IAEA activity for promoting the application of its Safety Standards is the provision of a large number of integrated safety review services. These include a wide range of nuclear safety services for operational nuclear installations, as well as assessments of radiological conditions and accidents. historical perspectives.

The IAEA's safety program is rooted in the late 1950s. Already in 1959, two years after the IAEA's creation, the United Nations Economic and Social Council asked the IAEA to establish recommendations for the safe transport of radioactive material. By March 1960, the first international measures for radiation protection and safety had been drawn up and were approved by the IAEA Board of Governors. The Regulations for the Safe Transport of Radioactive Material were established and first issued in 1961 (the latest revised edition was published in 1996).

The Board first approved Basic Safety Standards (BSS) for radiation protection in June 1962 (three revised editions have been issued since then, in 1967, 1982, and 1996).

The Basic Safety Standards. The latest edition of the BSS, entitled the International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Radiation Sources, is the product of extensive global co-operation. The BSS are jointly established together with five other organizations, including the International Labour Organization and the World Health Organization. They are among global organizations that have produced radiation protection codes and guides in support of the BSS in their respective spheres of activity.

The BSS and the Transport Regulations are the basis for national regulations in a large number of countries and are reflected in the regulatory documents of the major international bodies. Since their adoption, there is greater emphasis in many countries on reviewing and revising the relevant national regulations.

Over the years, the IAEA has developed and published families of radiation safety requirements and guides. Many of them now are being reviewed and revised so they are consistent with the latest edition of the BSS. A leading document in the field of radiation safety is the publication entitled Radiation Protection and the Safety of Radiation Sources, which covers areas of radiation protection, radiation safety, and transport safety. It was issued as a "Safety Fundamentals", or policy-level, document.

Nuclear Safety Standards. As nuclear power expanded globally, the need for a comprehensive set of nuclear power plant safety standards emerged. The IAEA's Nuclear Safety Standards (NUSS) program resulted in the development of a set of more than 60 standards (codes and supporting guides) dealing with the principal aspects of nuclear power plant safety, from siting through to operation. The NUSS documents also have become the basis for a number of national laws and regulations. A leading document in this field is the Safety of Nuclear Installations, which was issued as a "Safety Fundamentals" document and formed the technical basis for the Convention on Nuclear Safety, which entered into force in 1996.

Radioactive Waste Safety Standards. The first Safety Standards in this field were issued within a few years of the IAEA's creation. By the 1970s, a formal mechanism to review and supervise the production of safety standards on waste disposal had been established. By then, public concern over radioactive waste issues had increased and, as a means of demonstrating that there were already well-established methods for managing wastes safely, the IAEA created a high-profile document series called the "Radioactive Waste Safety Standards". The leading document, The Principles of Radioactive Waste Management, was issued in 1995. It formed the technical basis for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, which States adopted in 1997. Efforts now are focused on formulating harmonised standards in the area of radioactive waste safety, with the next years seeing the completion of the planned set of documents.

Steps Toward an International Safety Culture. Within the past decade, the IAEA set into motion a comprehensive review and strengthening of its safety program. This ongoing process has been, and continues to be, influenced by interrelated challenges. They are bound by the fact that safety is a dynamic, not static, concept which must remain in step with scientific and technical developments. In that context, standards taken alone or viewed in isolation are not enough to ensure achievement of higher levels of safety. It is important that safety standards are kept up-to-date and put into effect at the working level as part of an integrated approach and commitment to maintaining an international "safety culture".

As the main components of the international nuclear and radiation safety regime evolve, the IAEA's activities related to the preparation and application of safety standards may assume added dimensions. A number of major challenges and issues lie ahead. They include:

(a) Protection of the public in situations involving persistent (chronic) exposure to radiation. In particular, this concerns protection of people living in areas with high natural background radiation or with radioactive residues, e.g. from weapon testing or radiation accidents;

(b) Regulation of low doses of radiation. This includes the development of criteria for:

- exclusion (of radiation exposures which are not amenable to control) from radiation protection regulations;

- exemption (of small radiation sources) from regulatory systems of notification and control;
- exemption (of situations of low radiation doses) from intervention for reducing exposure.

(c) Strengthening the regulatory control of radiation sources and radioactive material. This issue includes:

- quantitative criteria for ensuring the safety of radiation sources;
- mechanisms for keeping the security of radioactive materials.

(d) Transport (including transboundary movement) of radioactive material. In particular, this includes:

- providing assurance that States are bound to the IAEA transport regulations; and peer review compliance with the regulations.

(e) Consolidation of international criteria for the safe disposal of long-lived radioactive waste:

- Management of safety at nuclear installations, including safety culture approaches.
- Influence on radiation and nuclear safety of the growing economic deregulation of markets.
- Improving communication of nuclear, radiation and waste safety issues.
- Radiation protection of patients undergoing radiodiagnosis and radiotherapy.
- Radiation protection of workers subject to relatively high exposure from natural sources.
- International approaches to radiation and nuclear emergencies, including response and assistance.

These issues and challenges are influencing the Agency's safety activities, including its safety standards program. It will be important to achieve international consensus on key issues in years ahead, and to clearly define priorities for future co-operative work. The continued support and involvement of governments and national and international organizations are instrumental to this process.

INTERVENTION PRINCIPLES — THEORY AND PRACTICE

P.H. JENSEN
Risø National Laboratory,
Roskilde, Denmark

M.J. CRICK
International Atomic Energy Agency,
Vienna

Abstract

INTERVENTION PRINCIPLES — THEORY AND PRACTICE.

After the Chernobyl accident, it became clear that some clarification of the basic principles for intervention was necessary as well as more internationally recognised numerical guidance on intervention levels. There was in the former USSR and in Europe much confusion over, and lack of recognition of, the very different origins and purposes of dose limits for controlling deliberate *increases* in radiation exposure for practices and dose levels at which intervention is prompted to *decrease* existing radiation exposure.

In the latest recommendations from ICRP in its Publication 60, a clear distinction is made between the radiation protection systems for a practice and for intervention. According to ICRP, the protective measures forming a program of intervention, which always have some disadvantages, should each be *justified* on their own merit in the sense that they should do more good than harm, and their form, scale, and duration should be *optimised* so as to do the most good.

Intervention levels for protective actions can be established for many possible accident scenarios. For planning and preparedness purposes, a generic optimisation based on generic accident scenario calculations, should result in optimised *generic* intervention levels for each protective measure. The factors entering such an optimisation will on the benefit side include avertable doses and avertable risks as well as reassurance. On the harm side the factors include monetary costs, collective and individual risk for the action itself, social disruption and anxiety. More precise optimisation analyses based on real site and accident specific data can be carried out and result in *specific* intervention levels.

It is desirable that values for easily measurable quantities such as dose rate and surface contamination density be developed as surrogates for intervention levels of avertable dose. However, it is important that these quantities should be used carefully and applied taking account of local conditions and the circumstances of the accident. Only with suitable models can they be accurately interpreted in terms of avertable individual or collective doses.

This paper will discuss the application of the basic radiation protection principles for intervention to develop generic intervention levels for different protection actions and how these levels can be converted to specific operational intervention levels reflecting site and accident specific factors. In addition, the factors entering the optimisation process will be discussed and also how the uncertainty associated with these factors will influence the optimised intervention levels. Finally, the use of intervention levels in the decision-making process after an accident is discussed.

1. INTRODUCTION

In the event of a nuclear accident or radiological emergency, there is a need for criteria for taking particular protective actions with the aim of avoiding or reducing radiation exposures to the population or to workers. Such criteria can be established on the basis of radiological protection principles for intervention situations. The effectiveness of measures to be taken to protect a general public will depend heavily upon the adequacy of emergency plans in which these criteria are specified. There is, therefore, an important role for planning in the establishment of *intervention levels* for different protective measures. It is of utmost importance that pre-established intervention levels form an integral part of an emergency response plan.

2. BASIC PRINCIPLES

2.1. Practices and interventions

In most situations in which there is a need to consider controls over people's exposure to radiation, the source of radiation is deemed to provide a net benefit to society, for which an increased radiation exposure can be justified. This is the case for all normal exposures as a result of industrial processes utilising radiation sources. These situations are defined as *practices* by the ICRP [7].

There are, however, a small number of situations in which the source of radiation exposure does not provide a net benefit. The aim of radiological protection in these circumstances is to reduce the exposure by taking some protective or remedial action. The two most easily identifiable examples of these situations are exposures resulting from the natural occurrence of radionuclides in the environment and exposures resulting from the release of radionuclides following an accident. These situations are defined as *intervention* by the ICRP [7].

Current radiation protection philosophy clearly distinguishes between a *practice*, which causes either actual exposures or probabilities of exposure and therefore will *add* radiation doses to the existing background, and *intervention* situations, in which radiation exposures can be reduced only by intervention in order to put exposed people in a better position. The radiation protection systems for practices and interventions are completely *separate systems*.

2.2. Principles for intervention

In existing exposure situations, i.e. existing at the time when control procedures are being considered, the choice of action is limited. The most effective action, that applied at the source, is rarely available and controls have to be applied in the form of intervention.

The system of radiological protection for intervention is based on the following general principles of *justification* and *optimisation*:

(a) *All possible efforts should be made to prevent deterministic effects.*

(b) *The intervention should be justified, in the sense that introduction of the protective measure should achieve more good than harm.*

(c) *The levels at which the intervention is introduced and at which it is later withdrawn should be optimised, so that the protective measure will produce a maximum net benefit.*

Dose limits used in the radiation protection system for practices do *not* apply in the case of intervention.

The process of justification and optimisation *both* apply to the protective action, so it is necessary to consider them *together* when reaching a decision. *Justification* is the process of deciding that the disadvantages of each component of intervention, i.e. of each protective action or, in the case of accidents, each countermeasure, are more than offset by the reductions in the dose likely to be achieved. *Optimisation* is the process of deciding on the method, scale and duration of the action so as to obtain the *maximum net benefit*. In simple terms, the difference between the disadvantages and the benefits, expressed in the same terms, e.g. monetary terms, should be positive for each countermeasure adopted and should be *maximised* by refining the details of that countermeasure's implementation.

The benefit of a particular countermeasure within a program of intervention should be judged on the basis of the reduction (*dose subtraction*) in dose achieved or expected by that specific countermeasure, expressed as an *avertable dose*.

2.3. Factors entering optimisation

The factors entering the optimisation process can be divided into those describing *benefits* from the countermeasure and those describing *harm*. In analysing the inputs to the decision on the introduction of countermeasures, it is necessary to decide on the relative importance of each factor. The most relevant factors are summarised below.

Benefit	**Harm**
Avertable individual risk	Individual physical risk
Avertable collective risk	Collective physical risk
Reassurance	Monetary costs
	Social disruption
	Individual disruption
	Countermeasure anxiety
	Worker risk

The weightings to be attached to each of these factors are necessarily subjective and it has been difficult to agree internationally upon their exact values. In any case the importance of some of the factors will vary with the site and nature of the accident, thus making it hard to generalise. Nevertheless, the dominant factors are those related radiological protection principles, and to psychological and political factors.

Socio-political and psychological factors indeed may well contribute to, or even dominate, some decisions. The competent authorities responsible for radiation protection should therefore be prepared to provide the radiation protection input (justification and optimisation of the proposed protective actions on radiological grounds) to the decision making process in a systematic manner, indicating all the radiological factors *already considered* in the analysis of the protection strategy. In the decision process the radiological protection and the political factors should *each* be taken into account *only once* to avoid the same political factors being introduced in several places.

2.4. Generic and specific intervention levels

In the management of accidents, there are two distinct phases in which optimisation of protective measures should be considered. In the phase of planning and preparedness, prior to any actual event, a *generic* optimisation of protective actions should be studied, based on a *generic* accident scenario. This should result, for each protective measure and each selected scenario, in an optimised *generic* intervention level, which is meant to be the first criterion for action to be used immediately and for a short time after the occurrence of an accident.

Some time after a real event, specific information on the nature and likely consequences of the accident would become available. In this case, a more precise and *specific* optimisation analysis can be carried out on the basis of actual data and efficiency of protective measures. This could result in a *specific* intervention level for each protective measure, to be used as a criterion in the medium and long term. However, in many cases the optimisation will be constrained by socio-political factors, which may make it difficult to alter the generic intervention levels unless there are overriding reasons.

3. SELECTION OF INTERNATIONAL GENERIC INTERVENTION LEVELS

3.1. Working Premises

Intervention levels for urgent and longer term protective actions can be based on the justification and optimisation principles and the following premises:

- national authorities will spend the same resources on radiation health risks as on other similar health risks;
- physical risks from the action are taken into account;
- disruption to individuals, such as livelihood or to resources, is considered;
- 'good' and 'harm' of psychological nature are excluded (although unpredictable, these are taken to result in a null net benefit);
- political, cultural, and other social factors (such as disruption) are excluded (because they will be considered separately).

The above relatively simple premises are considered appropriate to assist the selection of internationally applicable generic intervention levels. The premises have been used in Safety Series No. 109 [5] for the development of generic intervention levels. A variety of decision aiding techniques are available to assist in questions of social risk management, including cost-benefit theory, decision theory and social choice theory [9]. Cost-benefit theory was adopted in [5] as an appropriate rationale for assisting in the selection of generic intervention levels. This rationale was first adopted for the purposes of countermeasure decisions by [1]. The problem can be conceptualised in cost-benefit terms whereby the net benefit of a proposed action compared with taking no action can be expressed as:

$$B = \Delta Y - R - X - A_i - A_s + B_c \qquad (1)$$

where the six terms are expressions respectively of the radiological detriment averted by taking the action; the detriment associated with the physical risk of the action itself; the resources and effort need to implement the action; individual anxiety and disruption caused by the action; social disruption; and the reassurance benefit provided by the action. An intervention level (IL) for a countermeasure can be selected if principles (b) and (c) for intervention are satisfied. This can be achieved by conceptualising them as conditions that B must be greater than zero, and that $dB/d(IL) = 0$ respectively, and resolving the above expression accordingly.

3.2. Simplistic analysis

For clarity of expression and understanding a simplistic analysis was performed in the Annex of Safety Series No. 109 [5], expressing the terms in Eq.(1) in a way consistent with the premises described above. The two terms expressed quantitatively were the financial costs (X) and the radiological detriment averted ΔY). For illustrative purposes, the analysis for temporary relocation is considered below. The financial costs of temporary relocation can be expressed as the sum of one-off transport costs (away and return), loss of income per month, rental of substitute accommodation per month and depreciation/maintenance costs per month. The *average* cost per person was evaluated as between about \$400 and \$900 for the first month of relocation, and between about \$200 and \$500 for subsequent months [5].

The radiological detriment averted by temporary relocation was expressed simplistically in [5] as the product of the collective dose averted by the action and an ∀-value representing the resources allocated to averting unit collective dose. Several methods have been developed to assess how much value is placed by individuals and society on avoiding health detriment, including the human capital approach, legal compensation approaches, insurance premium analogies, implied or revealed preference approaches and willingness to pay approaches. There are flaws in all of these methods. Nevertheless it is possible to arrive at a credible range of values for α. The method used in [5] is based on the human capital approach used in [4] modified to take account of the 1990 Recommendations of the ICRP [7]. The average loss of life expectancy associated with 1 manSv of collective dose is estimated as 1 year. On a purely economic basis, a minimum value to be associated with a statistical year of life lost is the annual GDP per head. This was used in [5] to estimate a value for α of $20,000 per manSv saved. A factor of two uncertainty in the risk per unit dose was explicitly used in considering a range in the α-value from $10,000 to $40,000 per manSv. (NB All monetary costs are expressed for a highly developed country. The argument is not significantly different for less developed countries.)

On this basis the temporary relocation of people will be justified for more than one month if the avertable dose in that month exceeds IL_{rel}:

$$\frac{\$400 \text{ to } \$900 \text{ in first month}}{\$10{,}000 \text{ to } \$40{,}000 \text{ per manSv}} \approx \text{ten to several tens of mSv in the first month} \quad (2)$$

The optimum return time is when the avertable dose in a following month falls below IL_{rel}:

$$\frac{\$200 \text{ to } \$500 \text{ in the month}}{\$10{,}000 \text{ to } \$40{,}000 \text{ per manSv}} \approx \text{a few to a few tens of mSv in the month} \quad (3)$$

3.3. Sensitivity analysis

In support of the guidance in Safety Series No. 109 [5] more extensive sensitivity analyses were performed to consider explicitly the influence of the other relevant terms in Eq. (1). Moreover, several objections are raised and consequently modifications are often made to the basic value of α. Firstly, it takes no account of pain, grief and suffering associated with a premature death. Secondly, because people show an aversion to higher levels of individual risk, and because society is normally willing to allocate relatively more resources to protect people at higher risks, a modification is often used whereby α is increased according to the level of risk. Thirdly, an argument is made that because there is an inherent social time preference to speed up the receipt of desirable outcomes and postpone undesirable ones, a reduction factor should be applied to account for the delay between exposure and the occurrence of the effect. These three factors, which in some way counteract each other, could be assessed by willingness to pay methods. An example is given below of the influence the second two factors have on the range of intervention levels for temporary relocation.

Several national authorities provide guidance on the use of multipliers (so-called ∃-term) to apply to a baseline α-value to account for the level of individual dose received. [3] presents several schemes for such ∃-terms. One formulation can be expressed as:

$$\beta = \beta_o E^{v} \text{ where } \beta_o \text{ and } v \text{ are parameters} \quad (4)$$

Moreover a discount factor, F_d to account for the time delay between the dose received and the time of appearance of a cancer can be applied, of the form $(1+r)^{-T}$ where r is a discount rate (typically between 0 and 10% per annum) and T is the time delay. The detriment saved by invoking a countermeasure can be expressed then as :

$$\Delta Y = \alpha_o \beta_o F_D \left(E_{tot}^{v+l} - E_{res}^{v+l} \right) \tag{5}$$

where E_{res} and E_{tot} are the total doses received with and without the countermeasure. Temporary relocation, for example, can be suspended when :

$$\frac{\mathrm{d}\Delta Y}{\mathrm{d}t} = -C_{rel} = -\alpha_o \beta_o F_D (v+1) E_{res}^{v} E \tag{6}$$

where C_{rel} is the cost per person per month of continuing relocation. This can be solved depending on the relationship between the residual dose, E_{res} and the optimum dose rate for return, E. Various functional forms and source term characteristics were considered in support of Safety Series No. 109 [5]. Considering as an example a release of a single nuclide with an effective removal rate constant, 8, the optimum dose rate for return can be evaluated as:

$$IL_{ret} = \left(\frac{C_{rel} l^{v}}{a_o b_o F_D (v+l)} \right)^{\frac{l}{v+l}} \tag{7}$$

A parameter uncertainty analysis was carried out to evaluate the likely range of values within which a generic intervention level might reasonably lie, and to identify which

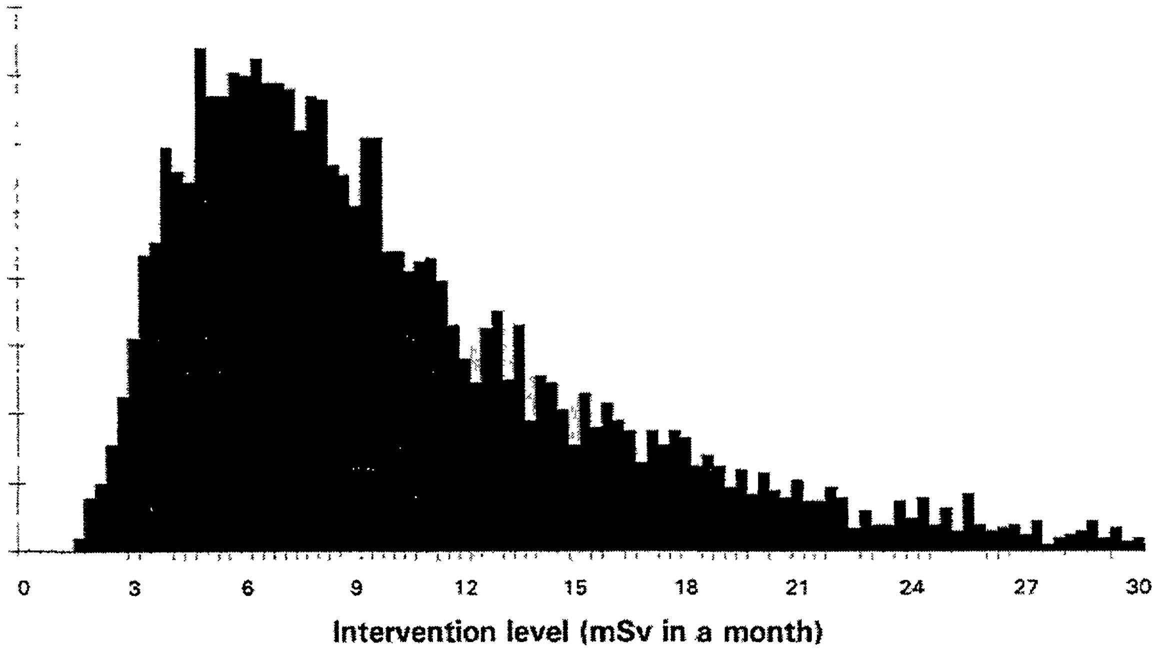


FIG. 1. Subjective expression of uncertainty in the generically optimised intervention level for return to an area from which people have been relocated. The probability distribution has been calculated using the program CRYSTAL BALL [CB93] from subjective expressions of uncertainty in the input parameters for Eq. (7).

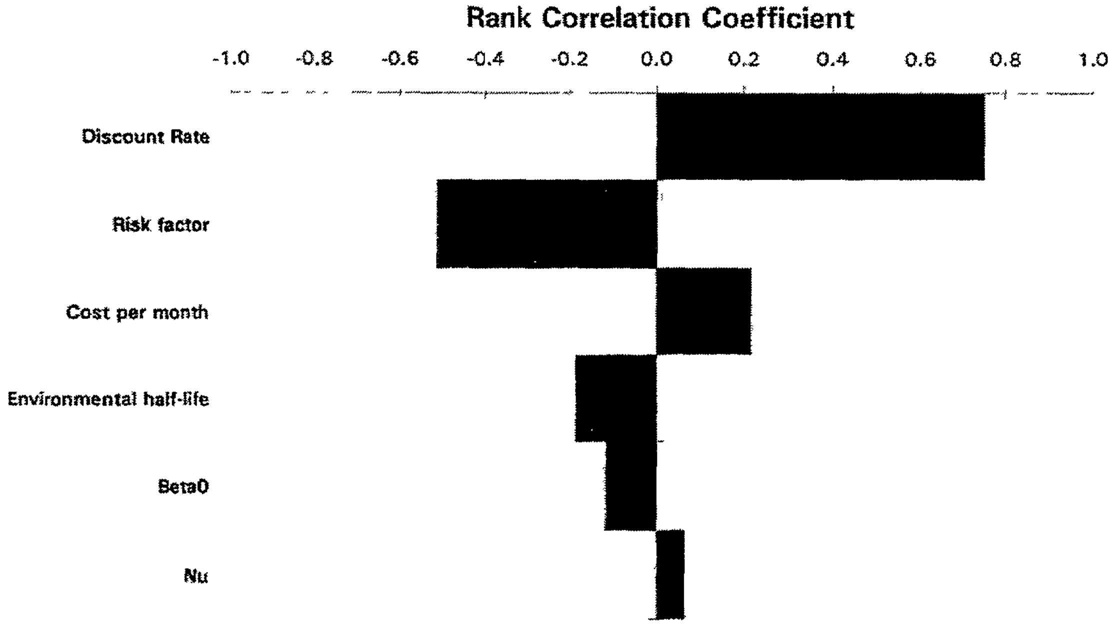


FIG. 2. The rank correlation coefficients between the uncertainty in the generically optimised intervention level and the uncertainty in the input parameters. The graph indicates that the uncertainty in the discount rate and the radiation risk factor are dominant.

parameter uncertainties influence most strongly the selection of a generic value. The results are illustrated in Figs. 1 and 2, and indicate that the range of values derived from the simplistic approach are not drastically different from those obtained by a more sophisticated approach. This analysis and others underpinned the final selection of the values that appear in Safety Series No. 109 [5], which also took into account qualitative factors.

3.4. Temporary and permanent relocation

Permanent relocation of a population can also be used as a protective measure where this action can be justified and optimised in accordance with the principles for intervention. Because the penalties associated with this action are of a one-off nature, the intervention level for permanent relocation is expressed in terms of total dose averted rather than avertable doses per month of temporary relocation. In addition to this criterion for permanent relocation based on avertable dose, there is a limit to the period of any temporary relocation that can normally be tolerated. The maximum length of this period is dependent on many social and economic factors. An argument based on economic grounds shows that continuing temporary relocation costs will begin to exceed permanent relocation costs between about one and five years. However social factors would indicate that the period of temporary relocation should be no more than a year or so.

The final guidance of the International Basic Radiation Safety Standards [6] is as follows:

The generic optimised intervention levels for initiating and terminating temporary relocation are 30 mSv in a month and 10 mSv in a month, respectively. If the dose accumulated in a month is not expected to fall below this level within a year or two, permanent resettlement with no expectation of return to homes should be considered. Permanent resettlement should also be considered if the lifetime dose is projected to exceed 1 Sv.

4. PRACTICAL USE OF INTERVENTION AND ACTION LEVELS

Intervention Level and Action Level are terms used for levels at which action is taken. The meaning of these terms have been differentiated in [6].

- Intervention Level is the level of avertable dose at which specific protective or remedial action is taken in a chronic or emergency exposure situation.
- Action Level is the level of dose, dose rate or activity concentration above which unspecified remedial or protective actions should be carried out in chronic or emergency exposure situations.

In other words, *Intervention Levels* refer to avertable doses by specific protective measures like relocation whereas *Action Levels* refer to several (unspecified) measures like agricultural countermeasures or radon reducing measures in houses [6].

Because of the inherent difficulty of forecasting doses that could be averted, there is a merit in establishing surrogate quantities that can be more readily addressed from conditions pertaining when decisions need to be made. For urgent decisions early on in the course of an accident, these conditions will primarily relate to conditions in the plant. Later on, operational quantities that can easily be measured will be of use, including air concentration, surface contamination density and dose rates. The relationship between these quantities and the avertable dose will vary considerably with the circumstances of the accident and nature of contamination. The operational quantities would, therefore, be both accident and site specific but would still be inextricably linked to the avertable dose.

OPERATIONAL INTERVENTION LEVELS

In general terms, the avertable dose, ΔE_{crp}, from exposure to a single radionuclide, *r*, and pathway, *p*, which could be averted by implementing a countermeasure, *c*, is given by the following *dose subtraction*:

$$\Delta E_{c,r,p} = E_{r,p} - E_{c,r,p} \qquad (8)$$

where E_{rp} is the dose without any countermeasure and E_{crp} is the dose after implementing the countermeasure, *c*. The avertable dose, ΔE_{cp}, from exposure to radionuclide, *r*, and *all exposure pathways* by implementing the countermeasure, *c*, can be calculated as the sum of avertable doses from each pathway, *p*:

$$\Delta E_{c,r} = \sum_p \Delta E_{c,r,p} \qquad (9)$$

If the radionuclide specific intervention level of avertable dose for the countermeasure, *c*, is IL_c, then the operational quantity, *q*, is the operational intervention level, OIL_{crq}, for countermeasure, *c*, and radionuclide, *r*:

$$\Delta E_{c,r}(q = Q_r) = IL_c \Rightarrow OIL_{c,r,q} = Q_r \qquad (10)$$

The intervention level in terms of avertable dose would determine the operational intervention level as follows:

$$OIL_{c,r,q} = \frac{IL_c}{\sum_p \Delta E_{c,r,p}(q=1)} \qquad (11)$$

It should be recognised that in the calculation of $\Delta E_{c,r,p}(q = 1)$, site specific parameters like location factors, filtration factors and indoor/outdoor occupancy have to be used.

RELOCATION

The avertable individual effective dose, ΔE, from relocation in a time period,)*t*, would be the sum of the external effective (-dose and the committed effective inhalation dose from resuspended radioactive material on the ground. The avertable individual doses in a month following the measurements of outdoor dose rate would - for ß-/γ-emitting radionuclides with a half-life of *months to years* like ^{103}Ru, ^{134}Cs and ^{137}Cs - be of the order of:

$$\sum_p \Delta E_{r,p}(q=1) \approx 200 \frac{\mathrm{mSv\,month^{-1}}}{\mathrm{mSv\,h^{-1}}}$$

The generic optimised intervention level for relocation, IL_{rel}, has been selected to be 30 for the first month and 10 mSv•month^{-1} in subsequent months [8, 5]. The operational intervention level for a continuing relocation after the first month, OIL_{rel}, for long-lived radionuclides can then be calculated as:

$$\mathrm{OIL}_{\mathrm{rel}} = \frac{\mathrm{IL}_{\mathrm{rel}}}{\sum_p \Delta \mathrm{E}_{c,r,p}(q=1)} = \frac{10\ \mathrm{mSv\,month^{-1}}}{200\ \mathrm{mSv\,month^{-1}} / \mathrm{mSv\,h^{-1}}} = \underline{50\ \mathrm{:Sv\,h^{-1}}}$$

In areas that have been contaminated with long-lived radionuclides, there would be an increasing residual dose after return to the area from a temporary relocation with increasing effective half-life of the deposited radionuclides. If the effective removal half-life were greater than about 6 years, the residual lifetime dose corresponding to a return criterion of 10 mSv/month would be greater than 1 Sv.

DECONTAMINATION

Decontamination of urban areas serves three main purposes: (1) reduce the individual doses to people living in the area, (2) accelerate the return time for people who have been relocated temporarily, and (3) avoid permanent resettlement. The optimum intervention criteria for clean-up operations would depend on many factors all of which are not easily quantifiable. The most important factors are the avertable individual doses to the population,)E_{pop}; the efficiency (fraction of activity removed or dose rate reduction factor) of the decontamination, *f*; the individual doses to the workers engaged in the clean-up, E_{work}; and the monetary costs of the cleaning operation, C_{clean}. The clean-up costs would include costs of labour, use of equipment, replacement of building materials, waste disposal etc.

Two different situations are considered here. Firstly, a residential area accidentally contaminated in which people can continue to live without any restrictions, and, secondly, a residential area accidentally contaminated from which people have been relocated temporarily.

NON-RELOCATED AREAS

Clean-up in non-relocated areas is justified if the monetary value of the avertable individual doses, ΔE_{pop}, by the clean-up exceeds the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation:

$$\alpha \ \Delta E_{pop} N_{pop} \geq \alpha \ E_{work} N_{work} + C_{clean} N_{pop} \qquad (12)$$

Assuming that the clean-up operation is implemented during a time period that is much less than the effective environmental removal half-life, $T_{1/2}$ (corresponding to an effective environmental removal rate constant of the contaminant 8), and that the time-averaged location factor for occupancy and shielding is L, the total avertable individual doses from the deposited activity can be expressed as:

$$\Delta E_{pop} = \frac{E \, L \, f}{\lambda} \qquad (13)$$

Decontamination is thus justified if the outdoor dose rate, E, at the time of decision of decontamination is greater than the Operational Intervention Level for clean-up, OIL_{clean}:

$$OIL_{clean} = E = \frac{\lambda}{L f}\left(\frac{N_{work}}{N_{pop}} E_{work} + \frac{C_{clean}}{\alpha}\right) \approx \frac{\lambda \, C_{clean}}{L f \alpha} \qquad (14)$$

The approximation can be made because the clean-up cost component, $C_{clean} N_{pop}$, normally is much greater than the equivalent cost of collective dose to the clean-up workers, $\forall_{work} N_{work}$.

AREAS FROM WHICH PEOPLE HAVE BEEN RELOCATED

Clean-up of areas from which people have been relocated is justified if the saved relocation costs by an accelerated return is larger than the sum of the monetary value of the collective dose to the clean-up workers and the cost of the clean-up operation:

$$C_{rel} N_{pop} \Delta\tau \geq \alpha \, E_{work} N_{work} + C_{clean} N_{pop} \qquad (15)$$

where C_{rel} is the relocation cost per person and unit time. The condition for clean-up is further constrained by an acceptable temporary relocation time, which without clean-up should be less than T_{max}. This maximum temporary relocation time would not be exceeded if the dose rate at the time of decision can comply with:

$$\dot{E} < OIL_{rel} \, e^{\lambda T_{max}} \qquad (16)$$

where 8 is the effective removal rate constant. If the dose rate exceeds this value, people should be permanently relocated. The accelerated return time,)t, is related to the effective environmental half-life of the deposited activity, $T_{1/2}$, as)t = -ln(f)•$T_{1/2}$/ln(2). The clean-up operation is justified, for a given efficiency, f, when the effective environmental half-life, $T_{1/2}$, exceeds:

$$\mathrm{OIL_{clean}} = \mathrm{T_{1/2}} = -\frac{\ln(2)}{\ln(f)}\left(\frac{\alpha}{\mathrm{C_{rel}}}\frac{\mathrm{N_{work}}}{\mathrm{N_{pop}}}\mathrm{E_{work}} + \frac{\mathrm{C_{clean}}}{\mathrm{C_{rel}}}\right) \approx -\frac{\ln(2)}{\ln(f)}\frac{\mathrm{C_{clean}}}{\mathrm{C_{rel}}} \qquad (17)$$

EXAMPLES

The parameters are assumed to have the following values:

N_{pop} = 10,000 people — α = \$ 20,000 per sievert

N_{work} = 100 workers — $L = 0.3$

E_{work} = 20 mSv per worker — $f = 0.5$

c_{clean} = \$ 200 per person — c_{rel} = \$ 200 per person per month

which can be used to calculate OILs for clean-up.

NON-RELOCATED AREAS

The Operational Intervention Level for clean-up of non-relocated areas contaminated with ^{137}Cs for which the effective removal half-life is assumed to be about 10 years can be expressed in terms of an external outdoor (-dose rate from Eq. (17):

$$OIL_{clean} = \frac{0.693}{10 \cdot 365 \cdot 24 \cdot 0.3 \cdot 0.5}\left(\frac{100}{10{,}000}0.02 + \frac{200}{20{,}000}\right) = \underline{0.5 \text{ :Sv h}^{-1}}$$

This dose rate is equivalent to a surface contamination density with ^{137}Cs of 0.4 MBq/m^2 (10 Ci/km^2).

AREAS FROM WHICH PEOPLE HAVE BEEN RELOCATED

The Operational Intervention Level for clean-up of areas from which people have been relocated can be expressed in terms of effective removal half-life of the deposited activity from Eq. (14):

$$\mathrm{OIL}_{\mathrm{clean}} = -\frac{\ln(2)}{\ln(f)}\left(\frac{20{,}000}{200}\frac{100}{10{,}000}0.02 + \frac{200}{200}\right) = \underline{1 \text{ month}}$$

Clean-up of areas from which people have been relocated would thus be justified if the effective half-life of the deposited activity is greater than 1 month, *and* if the foreseen relocation time is less than the maximum acceptable relocation time, T_{max}. In those situations, the outdoor dose rate would be larger than the OIL_{rel} for relocation, but lower than a value which — during the time period T_{max} — would decrease due to decay and migration to a value lower than OIL_{rel}. When the effective half-life in the environment would be larger than about six years, permanent resettlement would become necessary if the dose rate at the time, T_{max}, would be equal to OIL_{rel}, because the residual lifetime dose then would exceed 1 Sv. If the clean-up could reduce the surface contamination density so the residual lifetime dose would become less than 1 Sv, permanent resettlement could be avoided.

5. CONCLUSIONS

Over the past decade considerable progress has been made in developing and clarifying internationally recognised principles for decisions on protective measures following nuclear or radiological emergencies, and in providing quantitative guidance for applying these principles. However, experience has shown that, in spite of these efforts, there remain discrepancies in the application of both principles and guidance.

An accident resulting in the dispersion of radioactive material to the environment requires measures to protect the general public against the exposure to ionising radiation from the released and dispersed activity. The effective implementation of these measures will be largely dependent upon the adequacy of emergency response plans. Such plans should specify intervention levels for the various protective actions, and detailed considerations of site specific and accident specific conditions should be taken into account at the planning stage when specifying these levels based on the justification/optimisation principles.

In theory, the optimum intervention level for each kind of countermeasure could take a range of numerical values, depending on the exact circumstances following the accident and on social, political and cultural factors that national authorities might need to consider. However, to avoid confusion, there are obvious advantages to have a single internationally accepted value for the appropriate level of protection instead of a range of values as have been recommended earlier by international organizations.

Generically optimised intervention levels based alone on the premises presented in this paper might be used with equal benefit both in developing countries and in more developed countries, even if there are large differences in the absolute cost levels for specific countermeasures between such countries. The reason for this is that the outcome of an optimisation normally is a cost ratio, which is much less sensitive to geographical location than the absolute cost values alone all of which are similarly related to the GDP of the country.

Measurable quantities can be applied as surrogates for intervention levels using models that link avertable doses with these quantities. Modelling of the various processes describing the exposure of man to environmental contaminants would include parameters such as type of radionuclides, environmental half-lives, transfer functions as well as location and filtering factors for housing conditions. The models may be of varying complexity but both models and parameter values used to determine avertable doses should be realistic and particular to the circumstances under consideration. Incorporation of pessimism should be avoided by using central values from the parameter ranges. The measurable quantities normally used as so-called operational intervention levels include dose rate and activity concentration in air, in foodstuffs and on ground surfaces. The operational intervention levels will be both accident and site specific as they are derived from dose models that include accident and site specific parameters. Operational quantities should therefore be used carefully.

In conclusion, generic optimised intervention levels and their derived operational quantities based on the principles given in this paper are judged to provide protection that would be justified and reasonably optimised for a wide range of accident situations although they can only be used as guidelines. Any specific optimisation would lead to intervention levels that might be either higher or lower than those emerging from a generic optimisation.

REFERENCES

[1] BENINSON, D.J., GONZALEZ, A.J., Optimisation in Relocation Decisions, Optimisation of Radiation Protection, BEN86, Proc. IAEA/NEA Symp., Vienna, 10–14 March 1986, IAEA, Vienna (1986).

[2] CRYSTAL BALL, Version 3.0, Forecasting and Risk Analysis for Spreadsheet Users, CB93, Decisioneering, Inc., Denver, Colorado (1988–1993).

[3] COMMISSION OF THE EUROPEAN COMMUNITIES, Alara — from theory towards practice, CEC91, CEC report EUR 13796, Luxembourg (1991).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Assigning a Value to Transboundary Radiation Exposure, IAEA85, Safety Series No. 67, IAEA, Vienna (1985).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Intervention Criteria in a nuclear or radiation emergency, IAEA94a, Safety Series No. 109, IAEA, Vienna (1994).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, International Basic Safety Standards for Protection Against Radiation and for the Safety of Radiation Sources, IAEA94b, GOV/2715, Vienna, 11 April, 1994.

[7] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Recommendations of the International Commission on Radiation Protection, ICRP91, Publication 60, Pergamon Press, Oxford, New York, Frankfurt, Seoul, Sydney, Tokyo (1990).

[8] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Principles for Intervention for Protection of the Public in a Radiological Emergency, ICRP93, Publication 63, Pergamon Press, Oxford, New York, Seoul, Tokyo (1993).

[9] MERKHOFER, W., Decision Science and Social Risk Management, MERK87, D. Reidel Publishing Company, Dordrecht (1987).

MEASUREMENTS AFTER THE CHERNOBYL ACCIDENT IN RELATION TO THE EXPOSURE OF AN URBAN POPULATION

P. JACOB, R. MECKBACH
GSF — Forschungszentrum für Umwelt und Gesundheit,
Neuherberg, Oberschleißheim,
Germany

Abstract

MEASUREMENTS AFTER THE CHERNOBYL ACCIDENT IN RELATION TO THE EXPOSURE OF AN URBAN POPULATION.

After the Chernobyl accident *in-situ* gammaspectrometric measurements have been performed in Munich and in smaller towns in Southern Bavaria. At the measurement sites about two thirds of the total contamination was deposited by rain. For grassland, the attenuation of the radiation from ^{131}I, ^{103}Ru, ^{134}Cs, and ^{140}Ba due to the initial migration of the radionuclides in the ground and due to the surface roughness was found to be similar. However, large variations between the retention of the various elements on smooth surfaces have been observed. The absorbed dose-rate inside houses due to Chernobyl radionuclides was the range of one tenth to one hundredth of the absorbed dose-rate over open grassland, depending on the type of house and the location in the house, especially on the angle of view from the detector position to outside locations. The absorbed dose-rate in air due to caesium isotopes was measured over a period of 1 month to 8 years after the accident. To facilitate a use in models on radiation doses in urban environments, the time dependence of the results were approximated by analytical functions.

1. INTRODUCTION

The radiation exposure of the population after a contamination of an urban environment with caesium is dominated by the external irradiation (Amaral et al., 1991). Also for contamination of larger areas due to severe reactor accident the external radiation has been identified as the most important pathway for the exposure of the urban population (Kelly, 1987). This paper describes results on the behaviour of radionuclides which have been deposited after the reactor accident of Chernobyl in urban environments and on external exposures due to these radionuclides.

At the time t after a deposition of radionuclides, the **equivalent dose rate** $\dot{H}_{ni}(t)$ (ICRP 1991) in an organ n of a member of a population group i may be calculated by

$$\dot{H}_{ni}(t) = \sum_N A_N \cdot \dot{K}_{Nni} \cdot \exp(-\lambda_N \cdot t) \cdot r_N(t) \cdot \sum_j p_{ij}(t) \cdot f_{Nj}(t), \qquad (1)$$

where the summation index N indicates the N-th deposited radionuclide, λ_N the corresponding decay constant, and the summation index j indicates locations, where members of the population group i are assumed to have probabilities $p_{ij}(t)$ of stay. The other quantities in eq. (1) are discussed in the following paragraphs. Eq. (1) is applicable, if all relevant progenies in the detain chain of a deposited radionuclide can be assumed to be in radioactive equilibrium (Jacob et al., 1988). Otherwise, instead of the exponential factor in eq. (1) non-trivial time dependencies have to be taken into account (Jacob and Paretzke, 1988).

The **activity A_N of radionuclide N, deposited per unit area** on a reference site, may be determined with environmental samples or by *in situ* gamma-ray spectrometry.

Environmental sampling and measuring is laborious, especially when the activity per unit area on the reference site is inhomogeneous. The method is only recommended when an *in situ* gamma-ray spectrometry equipment is not available or when the knowledge about the activity distribution in the soil is considered to be too poor to derive reliable results from *in situ* gamma-ray spectrometry. *In situ* gamma-ray spectrometry is a powerful method to determine radionuclide activities per unit area (ICRU, 1994). In the first year after the deposition, the attenuation of the caesium radiation by the soil may be derived from the measured photon fluences in the 32 keV x-ray peak and in the 662 keV gamma-ray peak (Rybacek et al., 1992). Alternatively, information is derived from the ratio of the photon fluence in a peak to the fluence of scattered photons in a spectral window below the peak (Zombori et al., 1992; Hillmann and Jacob, 1994).

For members of a population group i standing on an open contaminated field, the factor $\dot{K}_{Nni}$ is defined as the **equivalent dose rate in an organ n per activity per unit area of a radionuclide N.** For adults $\dot{K}_{Nni}$ has been calculated by Eckerman and Ryman (1993) for plane sources on a smooth ground and for slab sources with a thickness of 1.5 cm and of 15 cm in a ground with a density of 1.6 $g{\bullet}cm^{-3}$. Petoussi et al.(1991) calculated $\dot{K}_{Nni}$ for foetuses, babies, children and adults for plane source in the ground below a slab of soil with a mass per unit area of 0.5 $g{\bullet}\,cm^{-2}$.

The factor $\mathbf{r_N(t)}$ is defined by the **ratio of equivalent dose rate per activity per unit area at the reference site and $\dot{K}_{Nni}$.** In the current approach open areas of grassland have been chosen as reference sites, and the equivalent dose rate factors $\dot{K}_{Nni}$ for plane sources in the ground below a slab of 0.5 $g{\bullet}cm^{-2}$ are used. For caesium, measurement results on the time dependence of $r_N(t)$ have been presented and analytically approximated in Jacob et al. (1994). Results for iodine, ruthenium, caesium and barium will be presented below. **Location factors $\mathbf{f_{Nj}(t)}$** are defined by the equivalent dose rate due to the radionuclide N at a location of type j relative to the reference site. This paper will mainly deal with measurement results for $r_N(t)$ and for outdoor and indoor location factors.

2. ABSORBED DOSE RATES IN AIR OVER OPEN GRASSLANDS

After the reactor accident of Chernobyl measurements were performed at several open areas of grassland in Bavaria, where more than 85 % (at one site (Giglberg) 77 ± 9%) of the activity was deposited with rain. The attenuation of the absorbed dose rate in air was determined by the following method: First, at each site 6 soil samples have been taken, each consisting of 5 soil cylinders, 15-20 cm deep and with a ground surface of 18 cm^2. The 5 cylinders have been taken from the edges and the center of a 10m×10m square. The ^{134}Cs activity per unit area was then obtained by gamma-spectrometric measurements of the soil samples. A_N was derived from this value by assuming relative activity depositions as measured in Neuherberg (Hötzl et al., 1987), taking into account that some weeks after the deposition the ^{140}La activity is by 15 % higher than the ^{140}Ba activity (Jacob and Paretzke, 1988). Second, *in situ* gamma-ray spectrometry was used to measure the unscattered photon fluence with energies of 365 keV for ^{131}I, of 497 keV for ^{103}Ru, of 796 keV for ^{134}Cs and of 1596 keV for ^{140}La. Using the assumption, that the radionuclide activity distribution has an exponential shape, which has been shown to be a good approximation for the first few years after a deposition (Jacob et al., 1994), the absorbed dose rates in air were calculated from the two sets of measurements. From the results in Table I two conclusions may be drawn:

i) The attenuation of the radiation from the different radionuclides is very similar. Therefore, for the first half year after the deposition $r_N(t)$ may be approximated by the same function for all relevant radionuclides.
ii) The values in Table I are close to unity, i.e. the observed attenuation of the radiation by surface roughness and by migration into the soil is the same attenuation as for plane sources in the ground below a slab of 0.5 $g \cdot cm^{-2}$ It may be concluded that the energy and angular characteristics for these radiation fields are similar, and that the measured attenuation of the absorbed dose rate in air may be directly used for the function $r_N(t)$.

TABLE I. ABSORBED DOSE RATE IN AIR AT OPEN GRASSLANDS IN SOUTHERN BAVARIA IN THE YEAR 1986 RELATIVE TO PLANE SOURCES AT A DEPTH OF 0.5 $G \cdot CM^{-2}$, AS DERIVED FROM MEASUREMENTS OF SOIL SAMPLES AND *IN SITU* GAMMA-RAY SPECTROMETRY. THE CALCULATED UNCERTAINTY OF THE GIVEN VALUES CORRESPONDS TO A STANDARD DEVIATION LESS THAN 15%, FOR VALUES IN PARENTHESES LESS THAN 20%.

Measurement Site	Date	Relative absorbed dose rate in air I-131	Ru-103	Cs-134	La-140
Neuherberg B	04 June	0 96	0 87	0 96	0 81
Neuhaus	04 June	1 08	1 02	1 02	0 81
Neuherberg C	09 June	0 99	0 87	0 96	0 81
Aurach	10 June	1 23	1 07	1 03	0 90
Giglberg	10 June	(1 19)	0 99	1 07	1 08
Neuherberg B	03 July	—	0 95	1 00	—
Neuherberg C	03 July	—	0 87	0 93	—
Grafing	04 July	—	0 74	0 85	0 70
Neuhaus	17 July	—	1 17	1 15	—
Aurach	17 July	—	1 01	0 97	—
Neuherberg B	08 Sep	—	0 81	0 91	—
Grafing	23 Sep	—	0 63	0 75	—
Neuhaus	30 Sep	—	1 13	1 04	—
Aurach	30 Sep	—	0 90	0 90	—
Bad Reichenhall	09 Oct	—	0 92	0 93	—
Neuherberg A	15 Oct	—	0 98	1 07	—

3. EFFECTIVE ACTIVITY PER UNIT AREA FOR PAVED SURFACES

Time series of *in situ* gamma-ray spectrometry measurements were performed at five sites in Southern Bavaria, which were covered by asphalt or pavements. The source at these sites was limited by houses or other structures. The measured unscattered photon fluences rates in air were multiplied by corresponding geometry factors (Jacob et al., 1990) to obtain an assessment for fluence rates over infinite places with the same covering and the same contamination. To approximate the effect of surface roughness and migration of the radionuclides in slits of the pavement, the geometry of a plane source covered by a slab with a mass per unit area of 0.16 g cm^{-2} was assumed. Under this assumption effective activities $\overline{A}_N$ per unit area were derived. By division with the activity A_N deposited on a close lawn an estimation for the retention of the radionuclides on the surfaces is obtained, which is called here relative effective activity per unit area. This quantity has been analytically approximated in the form

$$\overline{A}_N / A_N = a_1 \cdot \exp(-\ln 2 \cdot t / T_1) + a_2 \cdot \exp(-\ln 2 \cdot t / T_2) \qquad (2)$$

Results are given in Fig. 1 and in Table II.

TABLE II. PARAMETERS OF ANALYTICAL APPROXIMATIONS FOR RELATIVE EFFECTIVE ^{137}CS ACTIVITIES PER UNIT AREA.

Site		a_1	T_1(years)	a_2	T_2(years)
Coubertinplatz	A	0.22±0 02	0.31±0 05	0.15±0 02	2 3±0.3
Suma-Parkplatz	B	0.38±0 02	0.40±0.04	0 06±0.02	4 4±4.0
Färbergraben	C	0.21±0 01	0.16±0.02	0 13±0.01	2.1±0.2
Bad-Reichenhall	D	0.28±0.08	0.77±0.46	0.11±0.09	9 3±x*
Kreittmayrstraße	E	0.41±0.03	0.39±0.05	0.16±0.01	4.5±0.6

* $x > T_2$

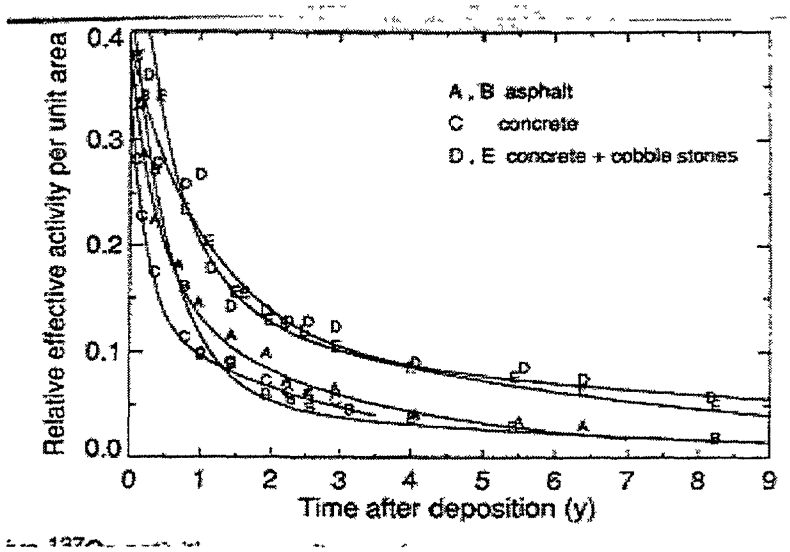


FIG. 1. Effective ^{137}Cs activities per unit area (see text) divided by the activity deposited per unit area by a wet deposition on a close lawn.

4. INDOOR LOCATION FACTORS

In situ gamma-ray spectrometry was performed at various indoor locations in three one-family houses and one multi-storey building. The results were normalised to the unscattered photon fluences over close areas of open grasslands. Results in Table III show how the attenuation of the unscattered radiation depends on the photon energy. In the attic of the one-family house Munich H, the 365 keV radiation is reduced by more than a factor of 3 stronger than the 1596 keV radiation. This is a combined effect of the better shielding for low energy radiation (Meckbach et al., 1988) and of the relatively low retention of iodine and also of ruthenium of roofs (Roed, 1987). In the administration building the 662 keV radiation was attenuated by a factor of four more than in the one-family houses. This difference is relatively small, because the detector was placed in the administration building not too far from large windows that reach from the ceiling to the floor.

TABLE III. UNSCATTERED PHOTON FLUENCES AT VARIOUS INDOOR LOCATIONS RELATIVE TO UNSCATTERED PHOTON FLUENCES OVER AN OPEN AREA OF GRASSLAND. UNCERTAINTIES OF THE GIVEN VALUE (EXPRESSED IN TERMS OF ONE STANDARD DEVIATION) ARE NOT GREATER THAN 15%, FOR THE VALUES IN PARENTHESES LESS THAN 20%.

house type /site / date of measurement	radionuclide / photon energy	location		
one-family house		ground fl	first floor	attic
Munich H	^{131}I / 365 keV	(0 050)	—	0 11
30 May 1986	^{103}Ru / 497 keV	(0 053)	(0 034)	0 13
	^{137}Cs / 662 keV	0 068	0 057	0 23
	^{134}Cs / 796 keV	0 066	0 052	0 22
	^{140}La /1596 keV	—	—	0 33
administration build		first floor	second fl	fourth floor
Neuherberg 11 June 1986	^{137}Cs / 662 keV	0 015	0 015	(0 014)
one-family house		ground fl	ground fl	first floor
Munich J	^{137}Cs / 662 keV	0 060	0 051	0 044
23 June 1986				
one-family house		ground fl	first floor	attic
Grafing	^{103}Ru / 497 keV	0 048	0 034	0 032
4 July 1986	^{137}Cs / 662 keV	0 057	0 046	0 066
	^{134}Cs / 796 keV	0 062	0 044	0 067

Extensive Monte-Carlo calculations have been performed to simulate the photon transport in urban environmental (Meckbach et al., 1988). Among the studied locations there were some, which were comparable to those, for which the gamma-ray spectra were measured. The calculated build-up factors and the location measured unscattered photon fluences were used to assess location factors. The results in Table IV confirm Monte Carlo calculations for wet depositions (Meckbach and Jacob, 1988).

TABLE IV. LOCATION FACTORS FOR VARIOUS INDOOR LOCATIONS. THE RESULTS WERE OBTAINED FROM *IN SITU* GAMMA-RAY SPECTROMETRY AND CALCULATED BUILD-UP FACTORS.

house type /site / date of measurement	radionuclide / photon energy	location		
one-family house		ground fl	first floor	attic
Munich H	^{131}I / 365 keV	(0 08)	—	0 11
30 May 1986	^{103}Ru / 497 keV	(0 08)	(0 06)	0 18
	^{137}Cs / 662 keV	0 11	0 10	0 32
	^{134}Cs / 796 keV	0 11	0 10	0 31
	^{140}La /1596 keV	—	—	0 45
administration build		first floor	second fl	fourth floor
Neuherberg	^{137}Cs / 662 keV	0 02	0 02	(0 02)
11 June 1986				
one-family house		ground fl	ground fl	first floor
Munich J	^{137}Cs / 662 keV	0 09	0 08	0 07
23 June 1986				
one-family house		ground fl	first floor	attic
Grafing	^{103}Ru / 497 keV	0 06	0 06	0 03
4 July 1986	^{137}Cs / 662 keV	0 08	0 08	0 08
	^{134}Cs / 796 keV	0 06	0 08	0 08

5. CONCLUSIONS

Equation (1) may be considered as the basic equation for assessments of external exposures of population groups. For a wet deposition of iodine, ruthenium, caesium and barium radioisotopes of grassland, the geometry of a plane source below a soil slab of $0.5\ g \cdot cm^{-2}$ was shown to describe well the radiation field in air. Therefore, if corresponding equivalent-dose rate factors (Petoussi et al., 1991) are used, a value of 1.0 for $r_N(t)$ is appropriate for the first months after a wet deposition.

Caesium was found to be removed effectively from surfaces covered by asphalt and paving in urban environments. Only about 2-3 % of the initial deposit is retained after some years on asphalt surfaces, the removal of this fixed component occurs with a half-life of a few years. For pavements the corresponding values are a retention of about 5 % and a half-life of several years. Measurements of indoor location factors confirmed previous Monte Carlo calculations.

A dominant part of the uncertainty of external exposures will generally be due to an appropriate description of the locations, where people stay, and of the time they stay at the various locations. These conditions will depend considerably on the country and the environment, where a larger contamination may occur, and have to be studied for each situation separately (e.g. Golikov et al., 1993; Erkin and Lebedev, 1993; Likhtariov et al., 1994).

ACKNOWLEDGEMENTS

The authors would like to thank Christa Schotola for performing *in situ* gamma-ray spectrometry measurements and computer calculations.

REFERENCES

[1] AMARAL, E.C.S., PARETZKE, H.G., PIRES DO RIO, M.A., CAMPOS, M.J., Radioecological measurements after the Goiânia accident, Proceedings of the 9th International Congress on Radiation Research, 7-12 July 1990, Toronto, Canada, (1991) 460–465.

[2] ECKERMAN, K.F., RYMAN, J.C., External exposure to radionuclides in air, water, and soil, Federal Guidance Report No. 12, US Environmental Protection Agency, Washington, DC 20460 (1993).

[3] ERKIN, V.G., LEBEDEV, O.V., Thermoluminescent dosimeter measurements of external doses to the population of the Bryansk region after the Chernobyl accident, The Chernobyl Papers, Vol. 1, Research Enterprises, Richland, Washington (1993) 289–311.

[4] GOLIKOV, V.Y., BALONOV, M.I., PONOMAREV, A.V., Estimation of external gamma radiation doses to the population after the Chernobyl accident, The Chernobyl Papers, Vol. 1, Research Enterprises, Richland, Washington (1993) 247–288.

[5] HILLMANN, U., JACOB, P., The peak-to-valley method for a determination of radionuclide activities in soil by in situ gamma-ray spectrometry, Preparation. (1994).

[6] HÖTZL, H., ROSNER, G., WINKLER, R., Ground depositions and air concentrations of Chernobyl fallout radionuclides at Munich-Neuherberg, Radiochimica Acta 41, (1987) 181.

[7] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, 1990 recommendations of the ICRP, Publication 60, Annals of the ICRP 21 No. 1–3, Pergamon Press, New York (1991).

[8] INTERNATIONAL COMMISSION ON RADIATION UNITS AND MEASUREMENTS (1994), Gamma-ray spectrometry in the environment ICRU Report 53, Bethesda, Maryland, to be published.

[9] JACOB, P., PARETZKE, H.G., ROSENBAUM, H., ZANKL, M., Organ doses from radionuclides on the ground, Part I: Simple time dependencies, Health Phys. **54** (1988) 617–633.

[10] JACOB, P., PARETZKE, H.G., Organ doses from radionuclides on the ground, Part II: Non-trivial time dependencies, Health Phys. **55** (1988) 37–49.

[11] JACOB, P., MECKBACH, R., MÜLLER, H.M., MEIMBERG, K., Abnahme der abgelagerten künstlichen Radioaktivität in städtischer Umgebung, GSF-Bericht 17/90, GSF–Forschungszentrum für Umwelt und Gesundheit, D-85758 Oberschleißheim, Germany (1990).

[12] JACOB, P., MECKBACH, R., PARETZKE, H.G., LIKHTARIOV, I., LOS, I., KOVGAN, L., KOMARIKOV, I., Attenuation effects on the gamma-dose rates in air after caesium deposition on grasslands, to appear in Radiat. Environ. Biophys. (1994).

[13] KELLY, G.N., The importance of the urban environment for accident consequences, Radiat. Prot. Dosim. **21** (1987) 13–20.

[14] LIKHTARIOV, I., KOVGAN, L., NOVAK, D., VAVILOV, S., JACOB, P., PARETZKE, H.G., Effective Doses due to the Chernobyl external irradiation for different population groups of Ukraine, Submitted to Health Phys. (1994).

[15] MECKBACH, R., JACOB, P., PARETZKE, H.G., Gamma exposures due to radionuclides deposited in urban environments, Part I: Kerma rates from contaminated urban surfaces, Radiat. Prot. Dosim. **25** (1988) 167–179.

[16] MECKBACH, R., JACOB, P., Gamma exposures due to radionuclides deposited in urban environments, Part II: Location factors for different deposition patterns, Radiat. Prot. Dosim. **25** (1988) 181–190.

[17] PETOUSSI, N., JACOB, P., ZANKL, M., SAITO, K., Organ doses of foetuses, babies, children and adults from environmental gamma rays, Radiat. Prot. Dosim. **37** (1991) 31–41.

[18] ROED, J., Run-off from and weathering of roof material following the Chernobyl accident, Radiat. Prot. Dosim. **21** (1987) 59–63.

[19] RYBACEK, K., JACOB, P., MECKBACH, R., In situ determination of deposited radionuclide activities: Improved method using derived depth distributions from the measured photon spectra, Health Phys. **62** (1992) 519–528.

[20] ZOMBORI, P., ANDRÁSI, A., NÉMETH, I., A new method for the detection of radionuclide distributions in the soil by in-situ gamma-ray spectrometry, Report KFKI-1992-20/K, Institute for Atomic Energy Research, Budapest (1992).

EARLY MEASUREMENTS AFTER THE GOIÂNIA ACCIDENT

J.M. GODOY, M.C.F. MOREIRA, E.S. DA FONSECA
Instituto de Radioproteção e Dosimetria,
Comissão Nacional de Energia Nuclear,
Barra da Tijuca, Rio de Janeiro,
Brazil

XA0054871

Abstract

EARLY MEASUREMENTS AFTER THE GOIÂNIA ACCIDENT.

During the early, intermediate late phase of the Goiânia radiological accident different survey methods were applied involving aerial and terrestrial (using a car and directly in the field) inspections. The present work aims to show how and when they were and the obtained results. Furthermore, the ^{137}Cs concentration in soils were determined using a NaI(Tl) spectrometer during the accident, and also in Rio de Janeiro in a high resolution gamma spectrometry system. The concordance among those results and the validity of the ^{137}Cs measurements in soil with NaI(Tl) are demonstrated.

1. INTRODUCTION

Not more than one day after the accident alarm the four main foci, as well as several secondary foci were identified (Fig.1). During this phase, simple hand monitors were used, and one can say, more as a way to confirm verbal information about possible contaminated places.

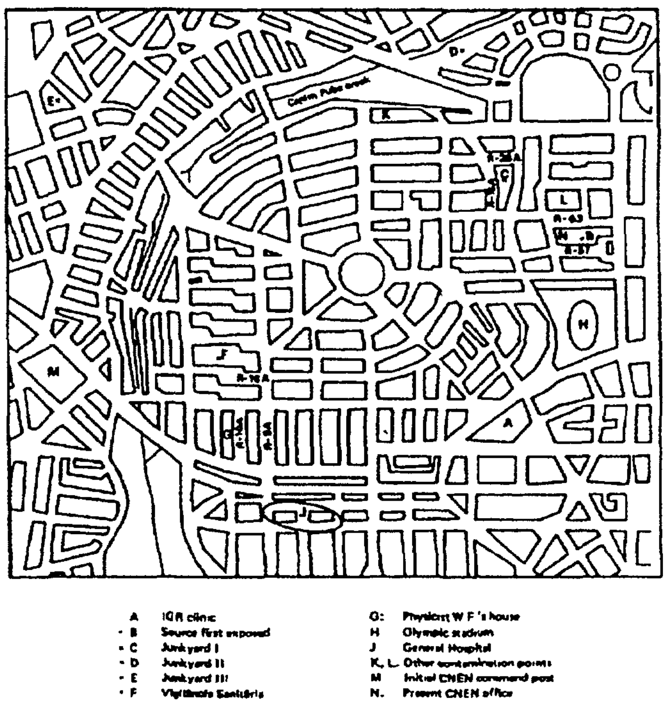


FIG. 1. Plan of Goiânia showing the principal sites of contamination.

After the first days of activities in Goiânia, other survey methods were introduced in order to produce a detailed figure about the main foci and to verify the presence or not of additional contaminated areas.

2. AERIAL SURVEY

During the course of the initial phase of the response, it was necessary to confirm that all the major sources of contamination had indeed been traced. To do this, an aerial survey of Goiânia was carried out.

A portable battery powered gamma spectrometer SCINTREX having NaI(TI) detectors with a total volume of 830 cm^3 was used. Most of the survey was flown at an altitude of 40 m and a ground speed between 50 and 70 km/h. A cycle of 80 m radius was effectively monitored and the sensitivity (two times the background) was 0.5 mSv/h at 1 m.

Over two days, all the urban area of Goiânia was monitored (about 67 km^2). This confirmed that no sites of major contamination had been missed, and one discrete spot was found that gave rise to a dose rate of 21 mSv/h at 1 meter. Figure 2 shows a typical analogue record obtained over contaminated areas.

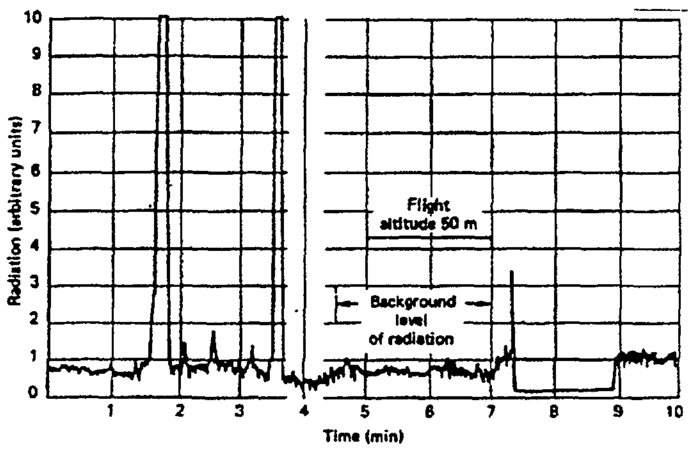


FIG. 2. A recorder trace from an aerial radiation survey. The background reading was taken at 50m altitude over open land away from the contaminated area of Goiânia. The peaks represent radiometric anomalies over contaminated areas.

3. SURVEY BY CAR

It is still possible that sites of lesser contamination had been missed by the aerial survey, especially in the vicinities of the heavily contaminated sites which gave rise to high background readings. A complementary system of monitoring that likewise could survey large areas, and was not as labour intensive as surveying with hand held instruments, was therefore necessary.

Two Geiger–Müller detectors were placed outside of a station wagon, 1m above the ground, covering an exposure rate range from 10^{-4} to 10^{2} mSv/h. To assure a rapid response to naturally occurring exposure rates, an additional 10^{2} x 10^{2} mm NaI(TI) detector was placed inside the vehicle 1m above ground (Fig.3).

All streets of Goiânia were travelled at a velocity of 20 km/h. At this condition, a 333 kBq source placed at the ground gave rise to a NaI(TI) count rate twice the normal background. Information concerning the locations with exposure rates greater than 10^{-3} mSv/h was entered into a data base.

The mobile survey was performed until March 1988 and covered a distance of 2000 km across Goiânia's streets, representing 80% of the city' urban area. Based on the

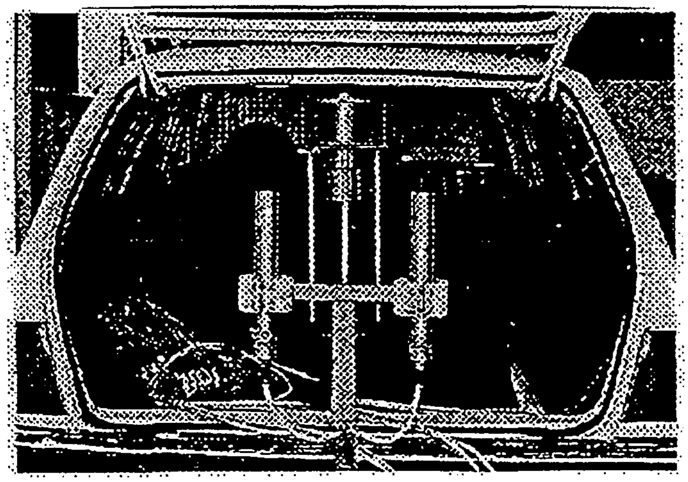


FIG. 3. Mobile radiation monitoring Nai and GM detectors mounted on a car.

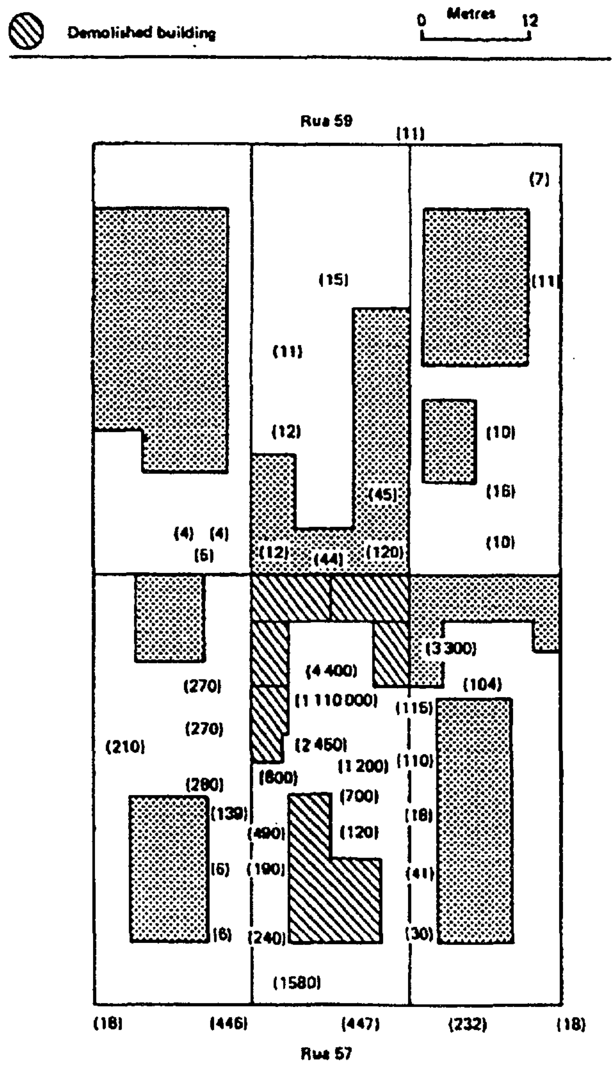


FIG. 4. Dose rates (in $\mu Sv\ h^{-1}$) around the house of R.A. in Rua 57 (57^{th} Street).

effectiveness of the mobile survey, this station wagon was integrated into the IRD/CNEN's emergency unit in early 1988.

4. HAND HELD SURVEY

In order to plan the intervention actions in the principal foci, an extensive measurement program was started aiming to obtain a more detailed picture of the contamination pattern in each place. Depending on the contamination level different monitors and detectors were used, ranging from scintillometers to teledectors. An example of the obtained pictures is shown in Fig.4.

5. ENVIRONMENTAL MONITORING

To quantify the environmental dispersion of caesium, more than 1300 measurements were performed in soil, vegetation, water and air samples. Emphasis was put on investigating areas near the main foci.

Initially, a multichannel analyser with a 5 cm x 5 cm NaI(TI) crystal was used at a special laboratory set up in Goiânia. However, it was found that a single channel analyser with a 7.5 cm x 7.5 cm crystal was sensitive enough for short (10 min.) counting times, since only

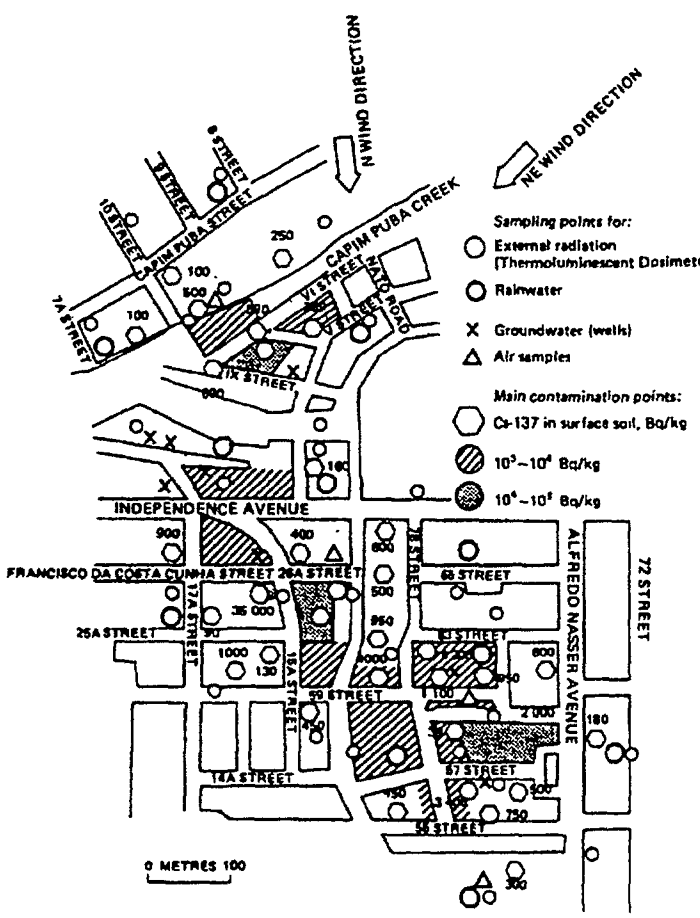


FIG. 5. Plan of the Aeroporto section of Goiânia showing the locations of the principal sites of contamination and the sampling points.

^{137}Cs was present. For soil samples with ^{137}Cs concentrations higher than 100 Bq/kg, a good correlation between the Goiânia measurements with NaI(TI) and those performed in Rio using germanium detectors was found. For lower values the ^{137}Cs concentration was over-estimated due to the interference of the 609 keV gamma ray of ^{214}Bi.

Based on the Goiânia measurements, among others, it was possible to show that:

- The surface soil contamination follows the wind pattern (Fig.5), showing the effect of resuspension and further dispersion.
- Leaf radioactivity closely paralleled that of the soil in level and distribution, owing to deposition of dust, a mechanism confirmed by the fact that washing reduced the contamination by 50%.

6. CONCLUSION

The survey methods applied during the Goiânia accident could be considered complementary one to the other, and were able to give a clear picture about the contamination in the city and to guide the further decontamination works.

However, until the construction of the final waste repository near the Goiânia city the ^{137}Cs question remains open for the local population.

REFERENCES

[1] ROSENTHAL, J.J., DE ALMEIDA, C.E., MENDONHA, A.H., The Radiological Accident in Goiânia: The Initial Remedial Actions, Health Phys. **60** (1991) 7–15.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA, Vienna (1988).

[3] BARRETO P.M.C., DA FONSECA, E.S., Levantamento Aeroradiom϶trico da Cidade de Goiânia ap∴s o Acidente com Cs-137, Proceedings of the Segundo Congresso Geral de Energia Nuclear, Vol.3, Rio de Janeiro, (April 1988) 47–57.

[4] MOREIRA M.C.F., Radiological Survey of Goiânia by a Mobile Monitoring Unit, Health Phys. **60** (1991) 81–85.

[5] GODOY, J.M., GUIMARvES, J.R.D., PEREIRA J.C.A., PIRES DO RIO, M.A., Cs-137 in the Goiânia Waterways During and After the Radiological Accident, Health Phys. **60** (1991) 99–103.

DOSE ASSESSMENT FOR DECONTAMINATION IN GOIÂNIA

E.C.S. AMARAL
CNEN–Instituto de Radioproteção e Dosimetria,
Rio de Janeiro, Brazil

XA0054872

Abstract

DOSE ASSESSMENT FOR DECONTAMINATION IN GOIÂNIA.

Shortly after the accident at Goiânia, the need arose to set derived intervention levels for the various exposure pathways to guide and optimise clean up measures. For the members of the critical group an intervention level of 5 mSv for the total effective dose in the first year after the accident was chosen, which then was subdivided into values of 1 mSv due to the contribution of external irradiation indoors, 3 mSv from external irradiation while being outdoors, and 1 mSv due to incorporation of resuspended particles and ingestion of locally produced food. The clean up indoors could be directed such that a pre-described ambient dose rate was no longer exceeded. These exposure levels and effective doses to the critical groups predicted in 1988 are compared to actual measurements made in 1988 to 1993 in a local house near one primary contamination foci, and best estimate. It can be shown that the actual doses received by members of the public living in the affected areas were significantly lower. The various reasons for this overprediction will be discussed.

1. INTRODUCTION

The ^{137}Cs radiological accident occurred in Goiânia and by its characteristics caused considerable concern to national authorities. Therefore the Brazilian Nuclear Energy Commission, CNEN, decided to adopt an annual exposure value of 5 mSv (for the first year) throughout the response of the accident to derive action levels in terms of measurable quantities (IAEA, 1988). Besides evacuation from some houses several remedial actions were taken at the first step of the response using heavy machinery. At the main contaminated region, within an area of 1 km^2 around the main foci, a recovery phase started later including soil, streets and house decontamination. The strong social and public pressure at the time decisions were made had forced the use of conservative approaches. Later on a best estimate of the radiation exposure some local measurements were performed. Here it will be discussed the dose criteria and models adopted for this phase of response, and their implication on the overprediction.

2. METHODS OF ACTION LEVELS DERIVATION

DOSE CRITERIA

An annual exposure level of 5 mSv was split in:

– mSv as an upper bound for external irradiation outside house (via soil);
– 1 mSv as an upper bound for external irradiation inside house (mainly due to roofs contamination); and
– 1 mSv for projection dose due to inhalation of resuspended material and ingestion of local food products.

MODELS ADOPTED

NDOOR EXTERNAL IRRADIATION

An occupancy factor of 0.5 was assumed and an action level of 0.5 μSvh^{-1} was derived giving allowance for background. The countermeasures were controlled with dose rate measurements.

OUTDOOR EXTERNAL IRRADIATION

Based on an occupancy factor of 0.5, an assumption of an infinite plane source and a natural background of 0.2 μSvh^{-1}, an action level of 1 μSvh^{-1} was derived, corresponding to 450 $kBqm^{-2}$ or 22.5 $kBqkg^{-1}$ of ^{137}Cs activity averaged over the uppermost 2 cm soil layer. The countermeasures were controlled with surface activity measurements since the dose rate measurements were influenced by the material present in other media, in particular, trees.

INTERNAL EXPOSURE

Based on the action level set for the surface activity in soil the projected dose was assessed using deterministic multiplicative models and considering the following pathways: inhalation of resuspended soil, and ingestion of vegetables, fruits, chicken, eggs and pork. The chicken contamination was considered to be only from soil ingestion, the vegetables deposition of resuspended soil and by root uptake and pork was considered to be contaminated through the ingestion of local non leafy vegetables (comprising 20% of the pigs daily diet). It was adopted a mean soil root zone concentration based on soil profile measurements (Amaral *et al.*, 1991), a resuspension factor of 10^{-7} m^{-1} and it was considered that a house garden production could support the annual consumption of a family.

3. RESULTS AND DISCUSSION

A probabilistic simulation of the effective dose (external and internal exposure) was performed based on the derived limit set for soil removal as the ^{137}Cs activity concentration in the house garden soils (Rochedo *et al.*, 1992). The parameter values used for the deterministic solution (conservative approaches) were adopted for most cases as a maximum value in the probabilistic simulation. Table I shows the results for both simulations.

TABLE I. RESULTS OBTAINED FROM PROBABILISTIC SIMULATION AND THE DETERMINISTIC SIMULATION FOR EACH EXPOSURE MODE FOR SOIL REMOVAL IN GOIÂNIA

Probabilistic simulation					**Deterministic simulation**	
Exposure mode	X50 (mSv)	SG	X95 (mSv)	X99 (mSv)	Dose (mSv)	X (%)
Internal	0 77	1 69	1 8	2 6	1	69
External	1 73	1 48	3 3	4 3	3	92
Total	2 63	1 36	4 3	5 4	4	92

For both exposure modes the 50th percentile is lower than the deterministic solution. However the external dose, which was of more concern at the time of the accident, has a deterministic solution corresponding to the 92nd percentile. This is due to the extreme value used for the outdoor occupancy factor of 0.5 instead of 0.33, and which also dominates the over prediction of the total dose.

Based on the contribution of each pathway to the radiation exposure, some local measurements were made after 1988. Average values were used in order to assess the radiation exposure to a family adopting more realistic population habits (Amaral *et al.*, 1992). The total dose ranges from 0.82 to 1.7$mSva^{-1}$ for a man and a child (5 years old), being the external exposure responsible for more than 95%. The lower values obtained are mainly due to the use of more realistic population habits not only the occupancy factor but also the products ingestion rate from a small garden production; also a smaller value for resuspension factor than predicted lead to a neglected inhalation pathway. As an example of measurable quantities and population habits used, Table II shows the dose results for adults working at home. A more realistic approach for the population habits could have lead to a small amount of soil removal.

TABLE II. DOSE RESULTS FOR ADULT WORKING AT HOME

Exposure Sources	Exposure Quantity	Daily Living Habits and Exposures			
Effective DE/kerma (Sv/Gy)		0.75			
	Excess K (nGy/h)	Exp. time (h/d)		Dose	
				(µSv/d)	%
Indoors at home	50	14		0.52	18.4
Outdoors in garden	200	5		0.75	26.3
Outdoors in Rua 57	1000	2		1.5	52.5
Elsewhere	0	3		0	
1. Total External Exposure		24		2.77	97.2
Inhalation DF (nSv/Bq)		9			
	Air Conc. (mBq/m^3)	T(h)	BR (m^3/h)	Dose	
Indoors at home	0.2	8	0.35	17.6	
		6	1.15		
Outdoors in garden	0.3	5	1.15	15.5	
Outdoors in Rua 57	1.5	2	1.15	31.0	
Elsewhere	0	3	0	0	
2. Total Inhalation Exposure		24		64.1	< 0.1
Ingestion DF (nSv/Bq)		14			
	Mass Conc. (mBq/g)	Daily Cons. (g/d)		Dose	
				(µSv/d)	%
Soil in playground/on food	10000	0.1		0.014	0.5
Own egg	25	50		0.017	0.6
Own chicken	50	30		0.021	0.7
Own vegetables	40	50		0.028	1.0
3. Total ingestion Exposure				0.08	2.8
Sum 1—3 (µSv/d):				2.85	100
Eff. DE/a (mSv/a):				1.04	

4. CONCLUSIONS

The use of more realistic population habits is recommended to be considered by the decision makers since the most countermeasures involve emotional, social and waste management costs.

REFERENCES

(1) AMARAL, E.C.S., VIANNA, M.E.C.M., GODOY, J.M., ROCHEDO, E.R.R., CAMPOS, M.J., PIRES DO RIO, M.A., OLIVEIRA, J.P., PEREIRA, J.C.A., REIS, W.G., Distribution of ^{137}Cs in soils for remedial action during the recovery phase of the incident, Health Phys. **60** (1991) 91–98.

[2] AMARAL, E.C.S., PARETZKE, H.G., PIRES DO RIO, M.A., CAMPOS, M.J., Radiological measurements after the Goiânia accident, Proceedings of the 9th International Congress on Radiation Research, July 7-12, Toronto (1992) 460–465.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The radiological accident in Goiânia, ISBN 92–0–129088–8, Vienna (1988).

[4] ROCHEDO, E.R.R., AMARAL, E.C.S., BARTELL, S.M., The Relative Significance of Pathways and Parameters for the Caesium-137 Soil Decontamination Scenario at Goiânia, J. Environ. Radioactivity **15** (1992) 171–183.

EARLY MEASUREMENTS IN URBAN AREAS AFTER THE CHERNOBYL ACCIDENT

XA0054873

I. LIKHTAREV, et al.
Scientific Center for Radiation Medicine,
Kiev, Ukraine

Abstract

EARLY MEASUREMENTS IN URBAN AREAS AFTER THE CHERNOBYL ACCIDENT.
This paper summarises the experience on the radioactive monitoring of the environment and population dose assessment provided in urban areas, mainly in Kiev, after the Chernobyl accident. It emphasises the need of several radiological teams, of the support from several institutions and of preparedness for a consistent database, dose assessment and criteria for decision making. Main results of measurements of gamma exposure rates, air, grass and food radioactive contamination are presented.

1. INTRODUCTION

Kiev is the biggest city in Ukraine, which is located in a distance of about 120 km from the Chernobyl NPP. The population in Kiev consisted of more than 3 mln people in 1986.

The intensity and the type of radioactive monitoring were very dependent on the phase of the Chernobyl accident [1]: super-early, iodine, phase of alternative dose-rate and formed radioactive track, long-lived debris phase. Each of these phases themselves (because of different time-interval and radionuclide composition in depositions) have been characterised by a different structure of internal and external sources of exposure [2].

Organizations which provided the radioactive monitoring of environment, foodstuffs and exposure of inhabitancies are shown on Fig.1. Two Ministers had been mainly responsible for more important types of monitoring. The first one was the State Committee on Hydrometeorology which controlled the radionuclide depositions on the ground and gamma-

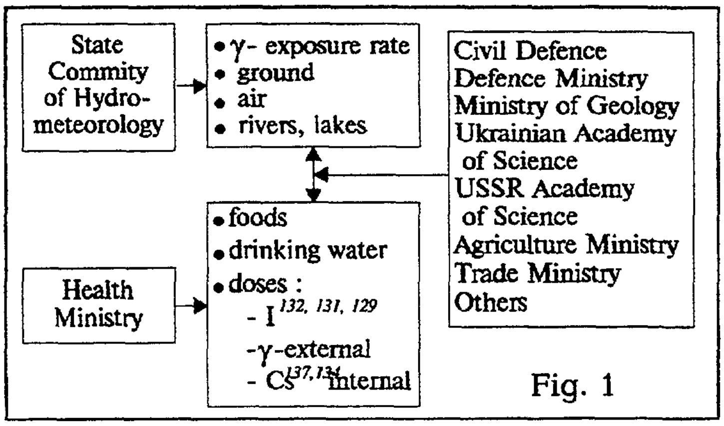


Fig. 1

exposure rate in the air. The second one was the Health Ministry which arranged the regulatory control on the exposure of members of the public, radioactive contamination of foodstuffs and drinking water.

Because of the very wide scale of the accident the radiological teams from Civil Defence and Defence Ministry as well as the radiological groups from the Ministry of

Geology and Scientific Institutes of Ukraine and former Soviet Union (Moscow, Leningrad, Cheljabinsk) also took part in providing the monitoring.

The **gamma-exposure rate** was measured by the groups from the State Committee of Hydrometeorology just after the accident. The results of daily gamma-exposure rate measurements at some meteorological areas in Kiev, nearest towns (Jagotin, Teterev) and in Chernobyl and Polesskoe (located at a distance of 40 km from Chernobyl) are presented at Fig.2. As it follows from these results the real increase of gamma-exposure rate in Kiev was registered not earlier than 30 April of 1986 (Southern track), but on the West track (Polesskoe) the exposure rate had been risen already on 26 April 1986. Besides, stationary investigation points for mass gamma-exposure rate monitoring had been created by the special radiological groups of "land control" and by the aerogamma-measurement's groups from

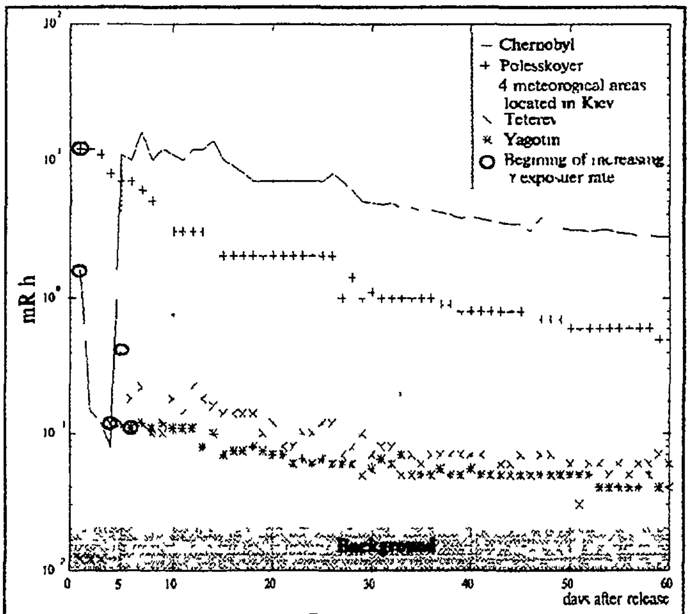


Fig.2.

Civil Defence and Chernobyl NPP on the whole territory of Ukraine including Pripjat town and the 30-km zone [3,4]. In Fig.3. the plan of Pripjat-town and the every hour gamma-exposure rate measurements points are shown. Those measure ments were made by two dosimetric teams (first one-o, second one-Δ). For some measurement points the time-dynamic of exposure rates are also presented. As it follows from the data the gamma-exposure rate in the Southeast areas of town at the time of evacuation rose 8 mGy h^{-1}.

β-emitters monitoring on the surface had been done mainly for the detection of small local radioactive spots. It was very important for the buildings which had been under the building (multiflats buildings, schools, kindergartens) and became very contaminated outside and inside. The discovered radioactive spots were than decontaminated by using special developed methods.

Permanent gamma-control of the tracks and cars which came in from the other territories had been provided at the special posts located just near the highways around Kiev and other big cities. At these posts the special wash-decontaminated systems were working. The main aim of those posts was the prevention of delivered radioactive contamination in the cities and towns.

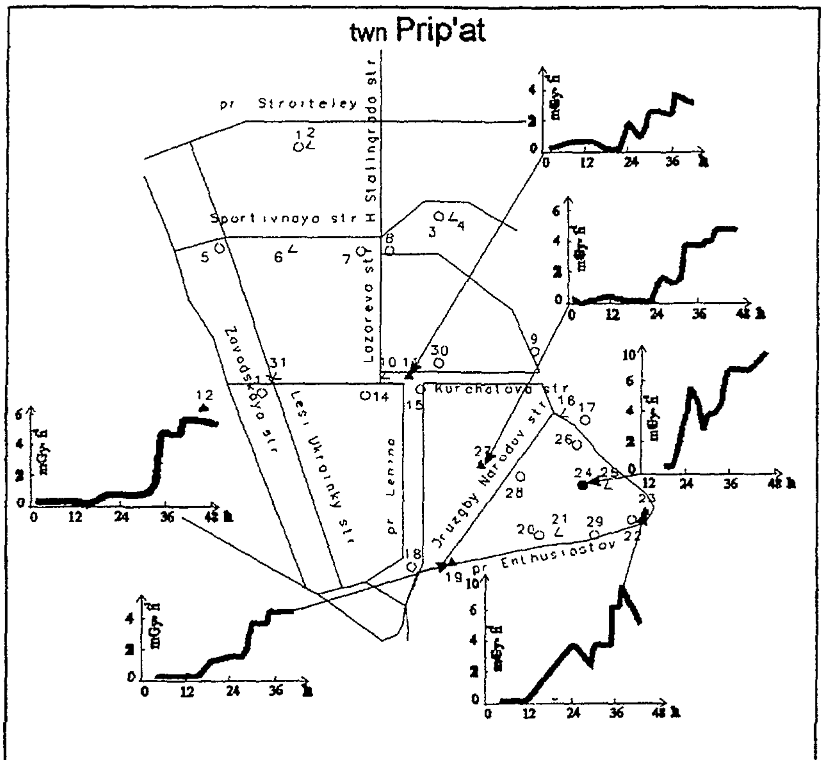


Fig.3.

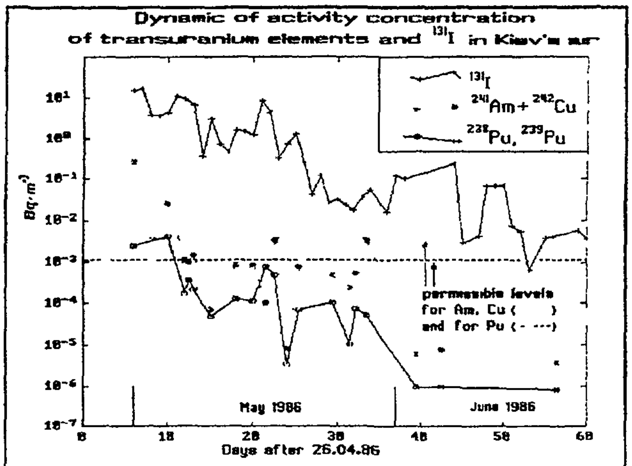


Fig.4.

Air radioactive contamination measurements which used sedimentation and aspiration methods had been provided at several points in Kiev. Some results of radioactive air measurements are presented on Fig.4. Specific activity in air for ^{131}I are presented without taking into account the retention coefficient of the filters. So the real concentration of ^{131}I in air may be in ten or more times higher.

The radioactive monitoring of leaves and grass in the green zones in Kiev made during the entire summer-time of 1986 (Fig.6.).

Foodstuffs and drinking water monitoring in Kiev had been organised by the Sanitary-Epidemiological stations which were under the Health Ministry and by the organizations which were responsible for the production and distribution of foodstuffs and drinking water. These were the Agriculture Ministry and the Trade Ministry.

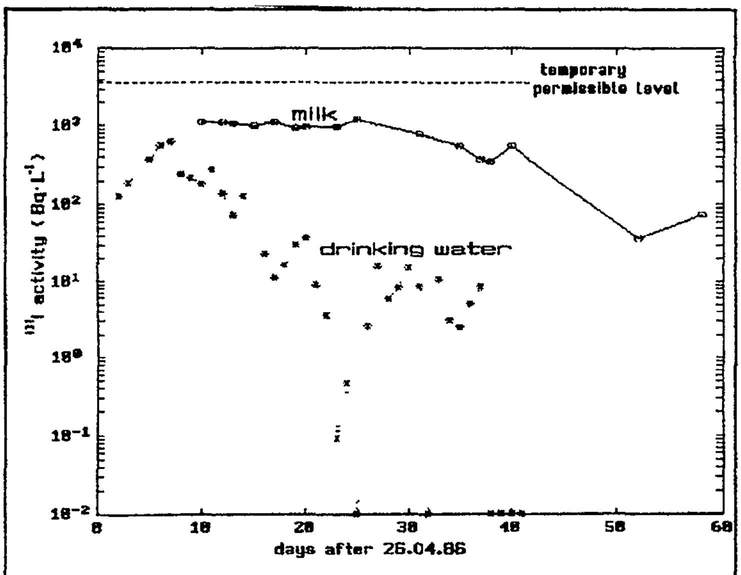


Fig.5.

The results of mass milk and drink water radioiodine monitoring in Kiev are shown on Fig.5. Two measurement systems were used, at that time, which were the energy- selected radiometers for mass screening and more precise gamma-spectrometry systems.

The special type of foodstuff control dealt with the permanent young bull radiocaesium body burden monitoring and monitoring of meat delivered to the province meat products plants. Besides, at all the agricultural food markets in Kiev and other towns the special groups, which provided the radioactive control of selling foods, had been organised. So only foodstuffs (vegetables, fruits, milk and meat products) which obtained the special radiological certificates could be sold.

The main results of the complex monitoring of air, water, soil, leaves, milk, meat and vegetables in Kiev at the early stage of the accident (May 1986) are presented in Fig.6. For all the soil and all the foods the ^{90}Sr. specific activity was at one-two powers low than the ^{137}Cs and ^{131}I specific activities.

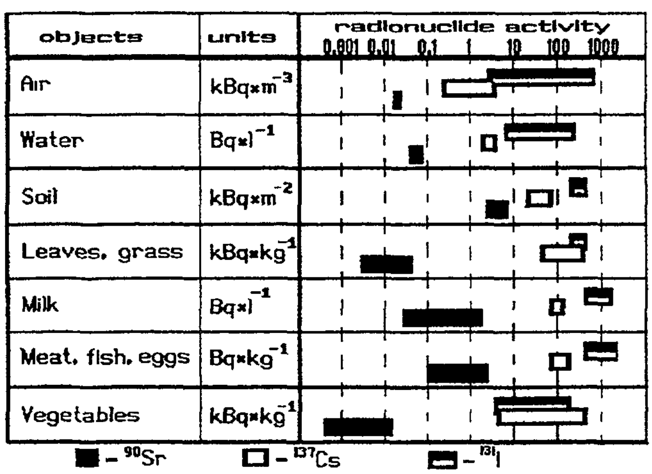


Fig.6.

Exposure of members of the public had been controlled by three types of permanent dosimetric monitoring.

• The assessment of external exposure of inhabitancies at the early stage (1986) made by calculation method, using the information on the gamma-exposure rate. (Fig.2.,3.) Later, those results had been used as the background for the evaluation of retrospective external exposure model parameters (behaviour coefficient, location and time factors [6]). First TLD measurements had been done among the inhabitancies of Polesskoe in September 1987.

• Thyroid exposure measurements were arranged by more than 100 dosimetric groups which provided the mass thyroid measurements among the inhabitancies of Kiev, another cities and settlements at the Ukraine during May–June 1986. [7,8]. As an example, the distribution of the results of those measurements for the children of Kiev are shown at Fig.7.

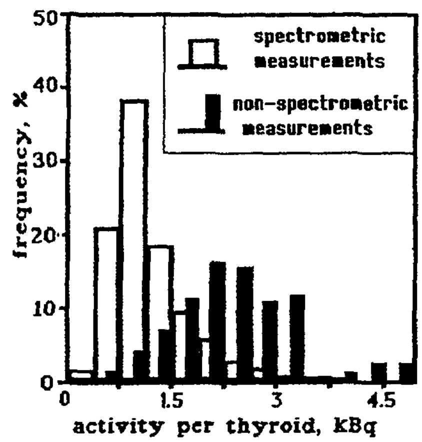


Fig.7.

• WBC-monitoring [4] of radiocaesium body burden among different population groups had been arranged just at the beginning of June 1986. Already in June 1986 the number of used WBC's (stationer, mobile and moving) exceeded the 54 units. The special system for their standardisation and intercalibration had been created. That system had four levels which were differentiated by the precision of WBC, their sensitivity and mobility. More than 140 thousand persons (90 thousands children) had been measured by February of 1987 at the contaminated territories.

2. CONCLUSIONS

It's very difficult to give a detailed description of the entire structure and all the equipment that has been used during the postaccidental monitoring after the Chernobyl accident. But now three very important conclusions may be drawn as a result of the Chernobyl experience.

• At the early stage of the accident thousands and millions of different types of measurements had been made. But a standardised common system for the selection of the more important types and the necessary scale of monitoring and control was absent. So, for instance, a lot of soil measurements had been examined, but at the same time extremely small measurements of air-samples were provided. That is why in cases where the main source of internal exposure was inhalation the dose reconstruction still left one very difficult problem.

• Absence of an automatic alarm-system made the quick reaction on the moving of radioactive cloud and changing the radioactive situation very difficult.

• At least, because of the absence of a good computer system for the fast estimation of the radiation and dosimetric situation, the main criterion for decision making was the qualification and skill of the experts (decision makers) who worked at different accidental centres.

REFERENCES

[1] LIKHTAREV I.A., et al., Decision-making problems in the event of major nuclear accident, Scientific Center of Radiation Medicine, Academy of Medical Sciences, Kiev. Open Problems of Human Radiobiology the Post Chernobyl. A Review by the Ukrainian Scientists at the Symposium, Influence of the Low Doses of Radiation on the Living Matter Rome, Sept.18-19, (1990) 13–25, Pacini Editore, Pisa (1993).

[2] LIKHTAREV I.A., KOVGAN L., et al., Main Problems in Post–Chernobyl Dosimetry. Assessment of the Health and Environmental Impact from Radiation Radionuclides, Proceedings of the International Workshop at Chiba, Inure 18–20, (1994) 27–51.

[3] LIKHTAREV, L., KOVGAN, L., et al., Effective doses due to the Chernobyl external irradiation for different population groups of Ukraine, Health Phys., (1994) (in press).

[4] PEREVOZNIKOV, O.N., LIKHTAREV, I.A., LITVINETS, L.A., JAKOVLEVA, G.N., Experience, Problems and Results of Mass Implementation of Whole-Body Counters at Post Chernobyl Period. Assessment of the Health and Environmental Impact from Radiation Radionuclides, Proceedings of the International Workshop at Chiba, January 18-20, (1994) 129–139.

[5] LIKHTAREV, ILIA A., CHUMAK, V.V., REPIN, V.S., Retrospective reconstruction of individual and collective external gamma doses of population evacuated after the Chernobyl accident, Health Phys. **66** 6 (1994) 643–652.

[6] LIKHTAREV, I., CHUMAK, V., REPIN V., Analysis of the Effectiveness of Emergency Countermeasures in the 30-km Zone during the Early Phase of the Chernobyl Accident, Health Phys., (1994) (in press).

[7] LIKHTAREV, I.A., SHANDALA, N.K., et al., Ukrainian thyroid doses after the Chernobyl accident, Health Phys., **64** 6 (1993) 594–599.

[8] LIKHTAREV, I.A., GULKO, G.M., et al., Thyroid doses resulting from the Ukraine Chernobyl accident, Part 1: Dose estimates for the population of Kiev, Health Phys., **66** 2 (1994) 137–146.

XA0054874

AGRICULTURAL PRODUCTION AS A SOURCE OF IRRADIATION OF POPULATIONS IN RADIATION ACCIDENTS

R.M. ALEXAKHIN
Russian Institute of Agricultural Radiology and Agroecology,
Obninsk, Kaluga Region,
Russian Federation

Abstract

AGRICULTURAL PRODUCTION AS A SOURCE OF IRRADIATION OF POPULATIONS IN RADIATION ACCIDENTS.

Radioactive contamination of the agricultural production sphere in case of a radiation accident with radionuclide release is one of the most important sources of additional irradiation for population. As a result, realisation of the measures for mitigating the consequences of the accident in agro-industrial complex assumes the leading role in total system of measures providing radiation safety. The possibility to obtain agricultural production meeting the radiological standards is one of the main indications of effectiveness of liquidation of the accident consequences.

First, obtaining of agricultural production meeting the radiological standards provides decreasing of the total radiation dose. The evidence is obtained in the 8-year experience of liquidation of the Chernobyl NPP accident that the 70% decrease of the internal dose for population became possible through a complex of protection measures in agriculture (during the first year after the accident, the contribution of internal dose into the total one amounted to 45%, and that of external irradiation — 52%; for the 70-year period these values are 39% and 60%, respectively). Second, the possibility to obtain "pure" agricultural production is one of the most important factors of psychological stability for population. Third, obtaining of consumable (as to radionuclide content) agricultural production in private small holdings is one of the guarantees of stability of demographic sector in the accident-affected zone.

From the point of view of organization of agricultural production in liquidation of the consequences of accidents with radioactive releases into environment, some periods can be distinguished:

- the first (early) period takes 10-12 days after the accident. The main measures in the field of agricultural production are in operative assessment of the radiological situation, organization of radiation survey, express classification of agricultural products ready to consumption. If radionuclide content in food products and feeds exceeds the DILs, their consumption is prohibited. The prophylactic measures to prevent adverse iodine effects are rendered a special place. If necessary, agricultural animals are relocated.
- the second period lasts 2-3 months after the accident. At that time radiological maps of contaminated lands are made, the system of radiation control of agricultural lands and agro-industrial production is perfected, the program of technological processing of contaminated agricultural products is implemented which guarantees obtaining of non-contaminated products.
- the third period is completed after the first 1.5 post-accident years. Agroamelioration measures are carried out at that time, the main scope of measures for detailed radiological survey of contaminated lands is realised; gradually the concept of production classification is replaced by the zonal production organization guaranteeing the Derived Intervention Levels established for the given period are not exceeded. The scientifically substantiated program of agricultural production management on contaminated lands for maximum possible obtaining of pure production and rational use of agricultural lands is formed.
- the fourth period starts in 1.5-2 years after the accident. In case that the deposited mixture of radioactive substances contains the log-lived radionuclides (^{90}Sr, ^{137}Cs. ^{239}Pu, etc.), the program of obtaining production meeting the radiological standards is realised as a constant long-term complex, in parallel with realisation of long-term system of agro-industrial measures, reorientation of agro-industrial production system and processing of contaminated products.

1. INTRODUCTION

In radiation accidents with radioactive releases into the environment, four main sources of the potential irradiation of man are formed: external irradiation due to immersion into the passing radioactive cloud, inhalation of radionuclides, external irradiation as a result of the contamination of different surfaces (living quarters, soil, etc.) and internal irradiation as a result of consuming the radionuclide containing products. Contribution of each of the above listed sources into total irradiation can range greatly, as dependent on numerous factors, the most important of these including the radionuclide composition of radioactive mixture deposited, scales of the accident and biogeochemical conditions of the environment. The list of other factors can include the population's alimentary habits, the season when the event of contamination took place, and some others.

As it is shown by the analysis of radiological situations connected with the most intensive additional effects of the radiation factor on man (global radioactive fallout after nuclear weapon tests, heavy radiation accidents in the South Urals in 1957 and at the Chernobyl NPP in 1986), as well as the investigation of different hypothetical scenarios of radiation accidents, the role of internal irradiation (i.e. that caused by consumption of radionuclide containing products) is considerable enough. Thus, during the first year after the accident at the Chernobyl NPP the contribution of internal irradiation into total dose burden for the population of the zone affected by the accident amounted to 45%, and that of external irradiation — to 52%; for the 70-year irradiation these contributions amount, respectively, to 39% and 60%. For the global radioactive fallout connected with nuclear tests the contributions of internal and external irradiation into total dose burden are approximately equal [1]. The internal irradiation as a component of the natural radioactive background is of particular significance (irradiation is caused mainly by inhalation accumulation of ^{222}Rn and its decay products). The value of internal irradiation is especially high in the case of a great contribution of long-lived β-emitters (^{90}Sr) into the mixture of radionuclides, as it was the case in the South Urals accident in 1957 or if iodine radionuclides are present in this mixture (the Chernobyl NPP accident in 1986).

The larger the accident scale is (the larger the contaminated area), the more important will be the role of internal irradiation in total radiation dose. Thus, after the accident in Goiânia in 1987 when the contaminated area had the form of spots in urban region (agricultural products were obtained only from gardens and kitchen gardens) and was characterised by relatively small absolute dimensions, the contribution of internal irradiation into total dose was estimated only of 20% [2].

2. DECREASING THE INTERNAL RADIATION DOSE

The main objective in liquidation of any radiation accident is to decrease radiation doses for the population staying in the accident affected zone, and those for specialists-liquidators. From this point of view, the liquidation of consequences of the accidental release of radioactive substances into the environment it should be stressed that the limiting of internal radiation dose is, as a rule, a more economically rational task than the limiting of the external dose (in the latter case, problems have to be considered such as removal of large amounts of contaminated soils, treating them as radioactive waste, etc.).

Decreasing the internal radiation dose as a component of total irradiation is connected with the organization of manufacturing the food products meeting radiological standards (permissible radionuclide content) on the contaminated lands. It is of great social and psychological importance for retention of the infrastructure of the agricultural sector on contaminated territories and for the prevention as well as the relief of radiophobia events which show up under the Chernobyl NPP accident. In this regard the organization of manufacturing "clean" products in individual farms is very important.

Decreasing internal irradiation doses for the population in contaminated regions could be achieved by several processes [3–6].

In the first place, at the acute phase in the first several weeks, several months after the accident the manufactured products with exceeding permissible levels of radionuclide content could be barred from use.

This measure is an exceptional one and has to be applied in extreme cases during closely limited times. From the first period of the accident it is of significance to reorient management of agricultural production so that obtaining the products with exceeding of (temporary) maximum permissible radionuclide concentrations has to be excluded.

Secondly, the purpose in limiting the doses of internal irradiation is attained at the cost of storage of products not meeting radiological standards (if short-lived radionuclides are present, for example, ^{131}I) or its processing which provides a decrease of radionuclide concentration in the end food product up to necessary levels (the most illustrative example is a processing of milk contaminated by ^{90}Sr and ^{137}Cs for butter which ensures a decrease of content of these radionuclides in butter up to 10 times and higher what was widely used by the accident in the South Urals and especially after the Chernobyl NPP accident).

Thirdly, in the end, one more method of decrease of dose influence on man from internal irradiation is an introduction of the system of protective measures on contaminated areas in agroindustrial production which are connected with the complex of ameliorative methods oriented on decrease of intensity of radionuclide migration through agricultural chains and reduction of radionuclide content in food products. As compared with the first two mentioned methods of decrease of internal irradiation dose which may be considered temporary and palliative the amelioration of contaminated lands and the system of corresponding countermeasures are to be considered as the basic strategic direction by organization of agroindustrial production after the accident under conditions of environmental contamination. Naturally that in this case the real situations and hypothetical scenarios are considered when in composition of contaminating radionuclide mixture the long-lived components (^{90}Sr, ^{137}Cs, ^{239}Pu and others) are present. Only based on introduction of this group of protective measures it is possible to achieve stable maintenance of agroindustrial production on the territories subjected to radioactive contamination.

3. AMELIORATIVE MEASURES

The range of ameliorative measures associated with introduction of measures on reduction of radionuclide content in agricultural products is sufficiently wide. In a general way these measures may be classified into two groups:

(1) measures on increase of soil production, crop yield and animal productivity by simultaneous reduction of radionuclide content in products, and

(2) special measures on reduction of radionuclide content in agricultural products (for example, application of ferrocyn as a food additive for agricultural animals what leads to reduction of radionuclide content (^{137}Cs) in milk and meat.

Decision making on the maintenance of a listed group of protective measures is to be carried out in long-term perspective not only on radiological indices but with regard to the social reasonability. Generally these decisions must be based on the conception risk-profit. By taking into consideration the evidence on liquidation of radiation accidents in the South Urals and at the Chernobyl NPP these measures are presented in Table I [7, 8].

Impact and effectiveness of changing land use .

Change	Reduction factor[a]	Social and economic consequences
Selection of other varieties of some crop	up to 2 - 4	very low
Selection of other, but comparable crops	up to 2 - 3	low
Green vegetables to cereals	up to factor of 5	high
Cereals to edible industrial crops, e.g., sugarbeets, oil seed	>> a factor of 10	low
Cereals to non-edible industrial crops, eg, flax	>> a factor of 10	low
Arable to cattle system	factor of 10 to 100	rather high
Sheep, goats to cattle	up to factor of 10	low
Dairy to meat system	highly dependent on technological possibilities	low
Arable system to forestry	>> a factor of 100	extremely high
Cattle system to forestry	>> a factor of 100	extremely high

$$^{a}\text{Reduction factor} = \frac{\text{activity concentration in alternative product}}{\text{activity concentration in original product}}$$

Realisation of protective measures in agricultural production in the region subjected to the influence of the accident at the Chernobyl NPP showed that on plowing lands ^{137}Cs concentration in the yield of main crops cultivated on contaminated areas decreased in the average by a factor of 2.2 and that on meadows and pastures where protective measures were realised — by a factor of 2.8 (average data on Russia during the first six years after the accident).

During the later period after the accident (if radioactive contamination of territory by long-lived radionuclides took place) the decision making for the decrease of dose loading on the population is based on conduction of long-term measures on limiting of radionuclide transfer into agricultural products. When total assessment of efficiency of protective measures in agroindustrial complex during all phases of the accident at the Chernobyl NPP was carried out the total decrease of effective equivalent dose on population living on the territory subjected to the influence of this accident will amount to about 30%. In this case of considerable significance are agroameliorative measures on meadows — critical ecosystem connected with production of milk — the basic dose-forming food product and to some extent that of meat. Effectiveness of complex of protective measures on the territory contaminated after the accident at the Chernobyl NPP is indicated in the Figure 1 which demonstrates a rapid decrease of milk and meat production (^{137}Cs content in them exceeds maximum permissible levels) during the first years after the accident. In 1993 on the territory of Bryansk region (Russia) in the most contaminated regions the total milk production with ^{137}Cs content higher than 370 Bq/l was below 2% (in these regions an intensive application of ferrocyn for reduction of ^{137}Cs concentration in milk is conducted).

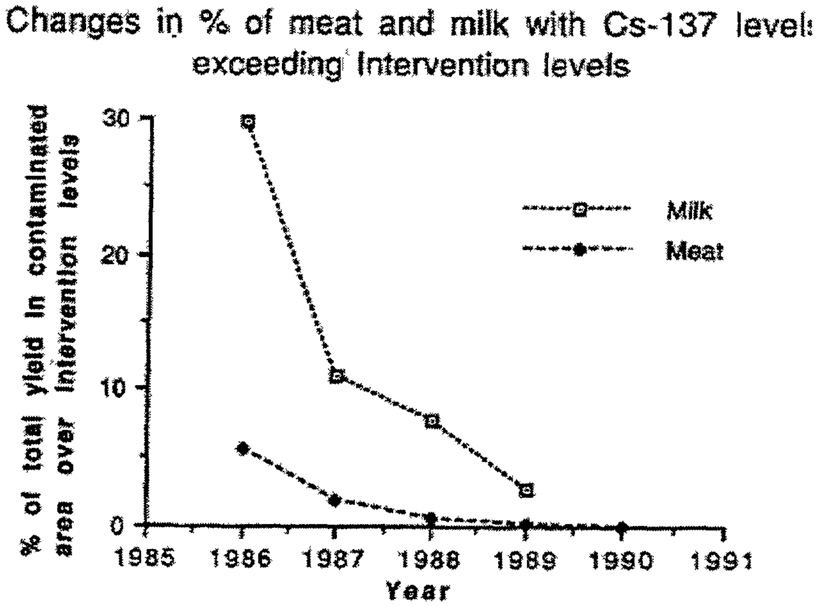


FIG. 1.

By decision making to rehabilitate contaminated areas and involving the return of the population previously settled out the estimation of effectiveness of countermeasures in agricultural production in long-term perspective is of great importance. It should be taken into account that after accidental radioactive releases into the environment sufficiently intensive "ageing" of radionuclides in soils — the basic depository for radioactive substances in agroecosystems — and decrease of biological availability of radionuclides for root assimilation were observed. Thus, total reduction of radionuclide content in agricultural products is a result of a decrease of biological radionuclide mobility following biogeochemical processes on the on hand and on the other hand the effect of protective measures in agriculture.

As the evidence of liquidation of the accident at the Chernobyl NPP shows the ecological half-lives (reduction of ^{137}Cs concentration in different agricultural products — milk, meat, grain, potato, vegetables and others — by a factor of 2) for the first 3–4 years after the accident are equal to 2-4 years and for 8 post-accidental years — up to 6-12 years ($T_{1/2}$ of ^{137}Cs is equal to 30 years). Contribution of protective measures and biogeochemical processes of decrease of ^{137}Cs mobility into total reduction of ^{137}Cs content in agricultural products is approximately equal and amounts to 48–49% whereas that of radioactive ^{137}Cs decay in this reduction is very small (of about 0.5%).

4. CONCLUSION

Assessment of real situations by liquidation of radiation accidents with radioactive releases into the environment and hypothetical scenarios of that kind of accident proves the importance of solving problems connected with maintenance of agroindustrial production in contaminated territories, limiting internal irradiation doses and elaboration of corresponding normative and recommendation documents as a part by decision making about consequences of accidental environmental contamination and providing radiation protection of the population.

REFERENCES

[1] UNSCEAR, Sources and Effects of Ionising Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly with Scientific Annexes, United Nations, New York (1993).

[2] AMARAL, E.C.S., et al,. Dose Assessment for Decontamination in Goiânia, Book of Abstracts, International Workshop on Scientific Bases for Decision Making after a Radioactive Contamination of an Urban Environment, Rio de Janeiro and Goiânia, Brazil, 29 August – 2 September (1994), 13.

[3] WILKINS, B.T., HOWARD, B.J., DESMET, G.M., ALEXAKHIN, R.M., MAUBERT, H., Strategies for Deployment of Agricultural Countermeasures, The Science of the Total Environment, V.137, (1993) 1–8.

[4] ALEXAKHIN, R.M., Countermeasures in Agricultural Production as an Effective Means of Mitigating the Radioecological Consequences of the Chernobyl Accident, The Science of the Total Environment, V.137 (1993) 9–20.

[5] PRISTER, B.S., PEREPELYATNIKOV, G.P., PEREPELYATNIKOVA, L.V., Countermeasures Used in the Ukraine to Produce Forage and Animal Food Produced with Radionuclide Levels below Intervention Limits after the Chernobyl Accident, The Science of the Total Environment,. V.137 (1993) 183–198.

[6] FIRSAKOVA, S.K., Effectiveness of Countermeasures Applied in Belarus to Produce Milk and Meat with Acceptable Levels of Radiocaesium after the Chernobyl Accident, The Science of the Total Environment,. V.137 (1993) 199–204.

[7] Guidelines for Agricultural Countermeasures Following an Accidental Release of Radionuclides, International Reports Series No. 363, Vienna (1994).

[8] ALEXAKHIN, R.M., FRISSEL, M.J., SCHULTE, E.H., PRISTER, B.S., VETROV, V.A., WILKINS, B.T., Change in Land Use and Crop Selection, The Science of the Total Environment. V.137 (1993) 169–172.

XA0054875

DISTRIBUTION OF EXTERNAL EXPOSURES IN THE RUSSIAN POPULATION AFTER THE CHERNOBYL ACCIDENT

M.I. BALONOV, V. YU. GOLIKOV, V.G. ERKIN, A.V. PONOMAREV
Institute of Radiation Hygiene,
St. Petersburg, Russian Federation

Abstract

DISTRIBUTION OF EXTERNAL EXPOSURES IN RUSSIAN POPULATION AFTER THE CHERNOBYL ACCIDENT.

The data of the monitoring of external exposure in the population of the Chernobyl accident area in Russia during seven years are presented. The deterministic model has been developed for estimation of the average dose of external exposure for different groups of urban and rural populations. The model has been verified with the results of over 10 thousand measurements of individual doses in inhabitants by means of thermoluminescent dosimeters. The stochastic model is being developed by forming the dose of external exposure in the population of a contaminated area, which allows to predict the dose distribution in critical groups of a population for the purposes of radiation protection.

1. INTRODUCTION

In the history of radiation accidents, one can distinguish at least three kinds of radioactive contamination of settlements. Chronologically the first accident was realised from 1949 in the basin of the river Techa (Cheljabinsk region, Russia), into which the waste products of the nuclear enterprise "Mayak" were poured. Radionuclides were present in the water and in river silt, and in the soil of flood-lands. The river and its flood-lands in villages were a narrow local source of exposure of people living near the river or visiting it. In Goiânia in 1987, several buildings and parts of urban area near them were subjected to accidental local contamination by powder of ^{137}Cs. Accordingly, the inhabitants of these buildings and visitors of the area were exposed. In the cases of wide-scale aerial contamination of areas due to nuclear explosions or serious accidents with the release of radionuclides' mixtures in the atmosphere (Kyshtym, 1957; Windscale, 1957; Chernobyl, 1986), settlements far from the source were contaminated, as a rule, homogeneously. The present paper is devoted to the description of regularities in forming the dose of external exposure in different categories of urban and rural population namely in the last situation, using the inhabitants of the Bryansk region of Russia as an example. It should be stressed that gamma radiation of radionuclides deposited on soil, artificial coverings, buildings and vegetation is the leading factor of exposure of the population after the Chernobyl accident.

2. MATERIALS AND METHODS

CHARACTERISTICS OF THE REGION AND OF THE FALLOUT

The south-west districts of the Bryansk region are located at a distance of about 200 km to the north-east of the Chernobyl nuclear power plant in the flat country. The dominating soil type is turf-podzol sandy and sandy loam, the annual quantity of precipitation is 500–700 mm. About half of the population of the area lives in villages in one– and two–storey brick or wooden houses and are involved mostly in agricultural activity. The second half of the population lives in small towns with the number of inhabitants from 10 to 70 thousand in multi-storey or separate houses and are employed mostly in industry.

The area of the Bryansk region was subjected to radioactive contamination as a result of rains from the radioactive cloud that passed over it on 28-29 April 1986. The isotopic composition of the fallout differs considerably from the initial composition of the release due to separation of refractory elements and decay of short-lived radionuclides. It is shown in Table I, according to the data of the Russian Hydrometeorological service [1]. The mapping of the area was performed with the ^{137}Cs surface activity (σ) on soil. The average σ in town Novozybkov is 0.7 MBq/m^2 for ^{137}Cs, and in the villages of the region — from 0.02 to 4 MBq/m^2.

TABLE I. RADIONUCLIDE COMPOSITION (REL. UN.) OF CHERNOBYL ACCIDENT RELEASE AND OF DEPOSIT ON RUSSIAN TERRITORY (TO 26.04.86)

Group of elements	Volatile				Intermediate					Refractory		
Nuclide	^{131}I	^{132}Te	^{134}Cs	^{137}Cs	^{103}Ru	^{106}Ru	^{140}Ba	^{90}Sr	^{89}Sr	^{95}Zr	^{141}Ce	^{144}Ce
$T_{1/2}$	8.04 d	3.28d	2.06y	30.0y	39.4d	386d	12.7d	50.2 d	28.5 y	64d	33d	284d
Entire Release	20	5	0.5	1.0	2.0	0.4	2.0	1.0	0.1	2.0	2.3	1.6
Bryansk and Tula Regions	11	(13)	0.5	1.0	1.7	0.5	0.8	0.2	0.02	0.05	0.11	0.07

METHODS OF MONITORING OF EXTERNAL EXPOSURE

During seven seasons of field investigations in the contaminated areas of Russia, over 1000 samples of virgin soil were taken and analysed. In each point, the surface activity of ^{137}Cs, depth distribution of activity in soil, and the dose rate in the air were determined. No considerable difference in the dynamics of the dose rate was found over turf-podzol soils of the Bryansk region and chernozems of the Tula and Orel regions.

Additional factors considerably influencing the dose of external gamma radiation are conditions of living and activity of a population in urban and rural environments. For the quantitative estimation of this factor, about 1000 urban and rural inhabitants of the Bryansk region were polled about their behaviour during different seasons. Simultaneously with the poll, the dose rate in typical points in the settlement and its surroundings was measured.

In experiments performed in natural conditions of the Bryansk region, anthropomorphic heterogeneous phantoms of an adult and of children between 5 and 1 years of age, were used. ***LiF*** thermoluminescent detectors were placed inside and on the surfaces of the phantoms. With the results of measurements, conversion factors were calculated from the absorbed dose in the air to the effective dose to men of different ages.

Measurements of individual doses were performed with ***LiF*** thermoluminescent detectors. The Harshow-2000D device was used to read the results. The lower limit of detection was 80 mkGy, the mean-root-square error of the dose measurement over 100 mkGy was about 10%, for lesser dose values it was up to 20%. Measurements of individual doses were done within a representative method. The population sample (about 50 inhabitants in the settlement) contained basic social and professional groups of inhabitants. Dosimeters were given to the population, as a rule, for one month. Conversion factors from the dosimeter readings to the effective dose were used to calculate the monthly effective dose; season variations of the external exposure were taken into account for the estimation of the annual effective dose. In all, about 100 settlements were investigated in the period from 1987 to 1993, about 10 thousand of values of individual doses were obtained.

3. RESULTS AND DISCUSSION

The deterministic model of exposure of different age and social groups of a population has been developed on the basis of literature data [2] and original experimental investigations in 1986-1993 [3, 4]. The average annual effective dose E_k in the k-th group of a settlement of inhabitants in the first approximation includes a dose rate in the air at the height of 1 m above an open plot of virgin soil $d(t)$; location factor LF_i equal to the ratio of the dose rate at the i-th typical plot in the settlement to $d(t)$; behaviour factor BF_{ik} equal to the part of time spent during a year at the i-th plot; conversion factor CF_{ik} from the absorbed dose rate in the air to the effective dose [3]:

$$E_k = \int_0^{365} d(t)dt \cdot \sum_i LF_i \cdot BF_{ik}, \mu Sv \quad (1)$$

From April-June 1986, short-lived radionuclides made a great contribution to the dose rate. This contribution was about 80% in May, 40% in June, and about 40% in the whole year 1986. Beginning from July 1986, in Russia, the dose rate was practically completely determined by the gamma radiation of ^{134}Cs and ^{137}Cs. Isotopic composition of fallout and initial dynamics of the dose rate are well known [1, 3] and were used in the model. In subsequent years parameters d(t) and d(t)/σ and location factors LF_i were determined with the help of multiple measurements. To estimate behaviour factors BF_{ik}, results of the population poll were used. The set of model (1) parameters is presented in [3]. The ratio of the effective dose to the dose in the air and on the body surface was determined from a series of experiments with the exposure of tissue equivalent phantoms. Appropriate conversion factors CF_{ik} were calculated for different age groups and typical locations. They are within the range 0.7-0.8 $Sv \cdot Gy^{-1}$ for adults, 0.85-0.95 $Sv \cdot Gy^{-1}$ for children of five years, and about 1 $Sv \cdot Gy^{-1}$ for children of one year.

About 10 thousand measurements of individual doses in inhabitants of the Bryansk region within the thermoluminescent technique in 1986-1992 [7] allowed to verify generalised dose reduction factors $RF_k = \sum_i LF_i \cdot BF_{ik}$ in different groups, see Table II. The results of TL-measurements showed a linear statistical connection of the dose with soil contamination σ , see Fig.1.

TABLE II. REDUCTION FACTORS RF_K FOR RURAL AND URBAN POPULATION

Population	Population groups			
	outdoor	indoor	school-children	representative group
rural	0.36*/0.31**	0.26/0.22	0.34/0.29	0.31
urban	0.25/0.20	0.20/0.13	—	0.20

* Wooden house

** Brick house

After the decay of short-lived radionuclides and an initial intensive migration of $^{134,137}Cs$ in the environment of settlements further dynamics of the dose rate are determined mainly by penetration of caesium radionuclides in the soil. An investigation of about 1000 soil samples during seven years was the basis for the model elaborated for convective-diffusive transfer and obtainment of two-exponential expressions for the average dose rate of $^{134,137}Cs$ gamma radiation in the open area [3]:

$$d(t) = d_0 \sum_{i=1}^{2} a_i \cdot \exp(-\ln 2 \cdot t / T_i), where \qquad (2)$$

$d_0 = 0.10$ (μGr/day)/(kBq/m^2);

$a_1 = 0.86$; $a_2 = 0.14$; $T_1 = 1.8$ years; $T_2 = 15$ years

Taking into account the modifying factors described above allows to estimate the effective dose in inhabitants during each year after the accident and to forecast it for the future the curve in Fig. 2. Generalised data of individual TL-dosimetry of Bryansk region inhabitants plotted in Fig. 2 as points are verification of the model. These points indicate average annual doses in rural population standardised to the s and obtained as a regression coefficient for dependence analogous to Fig.1 [4]. Good agreement of the results of calculated and instrumental dosimetry gives confidence in validity of the dose estimation during the time period elapsed after the accident, and its prognosis for 70 years.

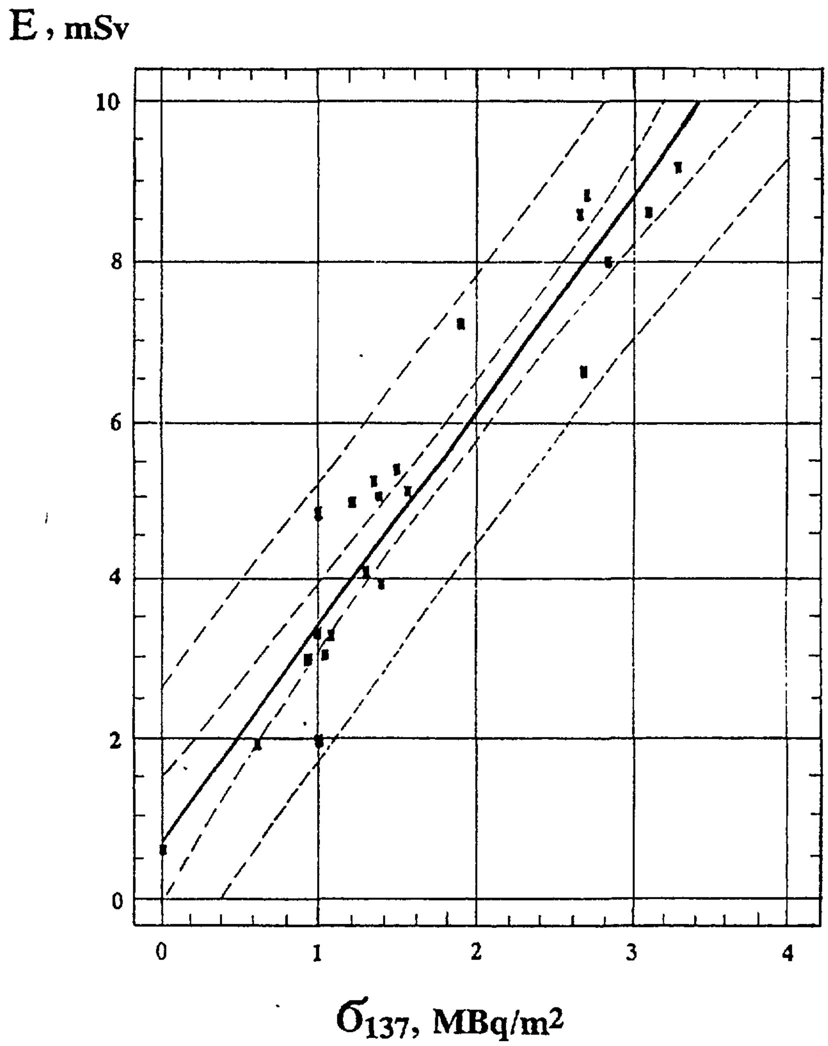


FIG. 1. Dependence of average annual effective dose of external gamma radiation E in Bryansk localities on the density of ^{137}Cs surface activity on soil σ.

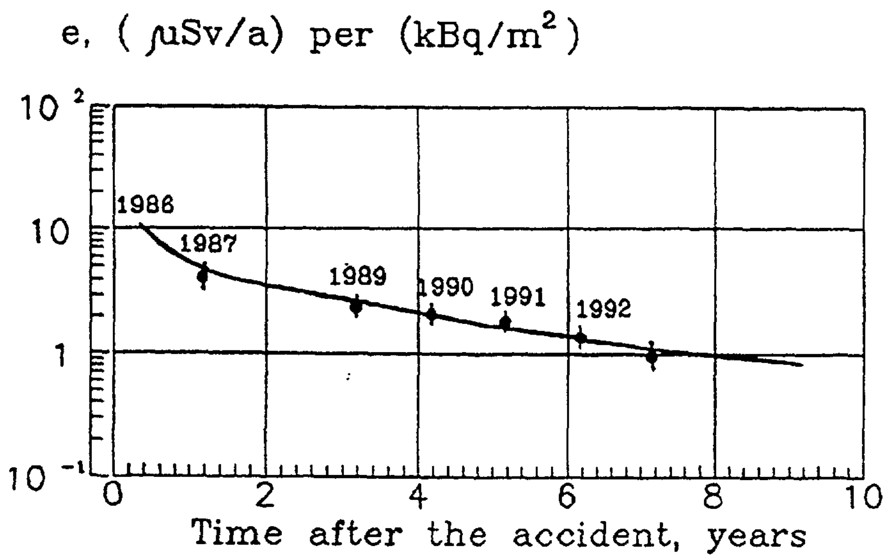


FIG. 2. Time dependence of standardised annual effective dose of external gamma radiation in rural population of Bryansk region.

Actually, during the eight years after the accident, the average dose of external gamma radiation in inhabitants of different villages of the investigated region was from 1 to 100 mSv, and in the critical groups (foresters, herdsmen) — up to 150-200 mSv. The average dose in inhabitants of the town of Novozybkov is about 13 mSv. According to the dynamic model, during eight years the population has received 60-65% of the life time dose of external gamma radiation.

Stochastic model. Actually, all natural and social processes of forming the dose of external gamma radiation in inhabitants of the contaminated area have a probabilistic character, and parameters describing them have considerable uncertainty. Finally, the probabilistic character of the processes of forming the dose causes uncertainty of the basic dosimetric value, the effective dose of external gamma radiation in persons living in a specific settlement and entering a specific social group. The characteristics of this uncertainty in the form of the frequency distribution of the annual individual dose measured with TLD in inhabitants of the town of Novozybkov and a number of villages, and its parameters normalised to the surface activity σ are presented in Figs. 3 and 4. Both distributions have a lognormal form with the following parameters: the mean geometric in town in 1991 1.0 $mSv \cdot m^2 \cdot MBq^{-1}$, and the standard deviation 0.4 $mSv \cdot m^2 \cdot MBq^{-1}$; in villages in 1989 3.8 and 1.8 $mSv \cdot m^2 \cdot MBq^{-1}$, respectively. The contribution of the inaccuracy of the TLD-method to the uncertainty of the dose should be taken into account. The average normalised dose in the inhabitants of the town in 1991 is by 3.8 times lower than the dose in rural machine-operators in 1989. The coefficient 1.7 of this relation is attributed to the decay of ^{134}Cs and ^{137}Cs nuclides and their deepening into soil during two years, and the coefficient 2.2 — to the difference in urban and rural conditions and in the way of life of the considered social groups. To model adequately the probabilistic process of forming the dose, it is necessary to take into account the stochastic nature and quantitative uncertainty of each parameter of the formula (1). Such stochastic model is being developed presently by the authors together with P. Jacob (GSF, Munich). As an example, Fig. 5 presents experimental data for one of the links of the model — the frequency distribution of location factors in town. As it is seen from Fig. 5, the values of the location factors are distributed close to the lognormal law with the variance factor within the limits from 0 5 to 1.0, which can considerably influence the distribution of the dose in inhabitants of the town. Similar information has been collected for all basic links of the model. In the completed form, the stochastic model will allow not only to estimate and predict the average dose in different groups of urban and rural inhabitants, but the frequency distribution of the individual dose. Such probabilistic characteristics are important for radiation protection of population, in particular, for the choice of critical groups of population and standardisation of their exposure with respect to possible deterministic effects.

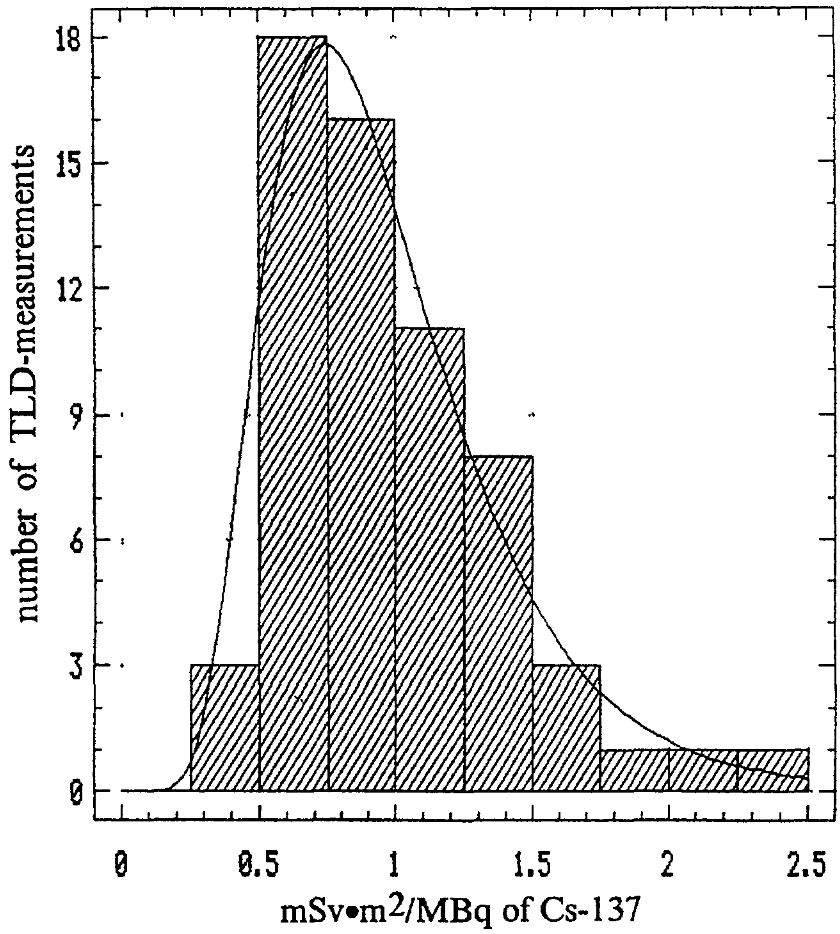


FIG 3 Distribution of standardised external dose in Novozybkov adult inhabitants in 1991 according TLD-measurements

4. CONCLUSIONS

The regularities and levels of external exposure in inhabitants of the Chernobyl accident in Russia has been studied experimentally. The deterministic model for estimation, reconstruction and prediction of the effective dose in different groups of urban and rural population has been developed. The model has been verified by means of about 10 thousand individual measurements of the dose with the TLD–method. The average dose during eight

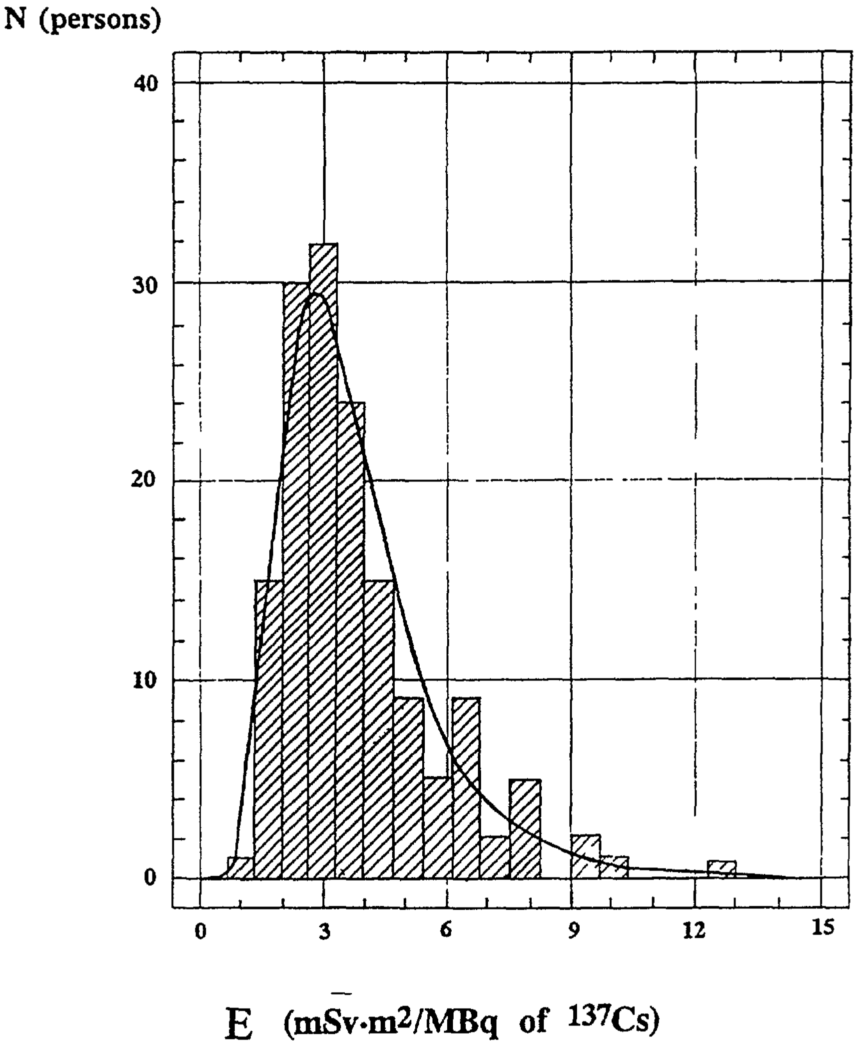


FIG 4 Distribution of standardised external dose in rural tractor-drivers in 1989 according TLD-measurements

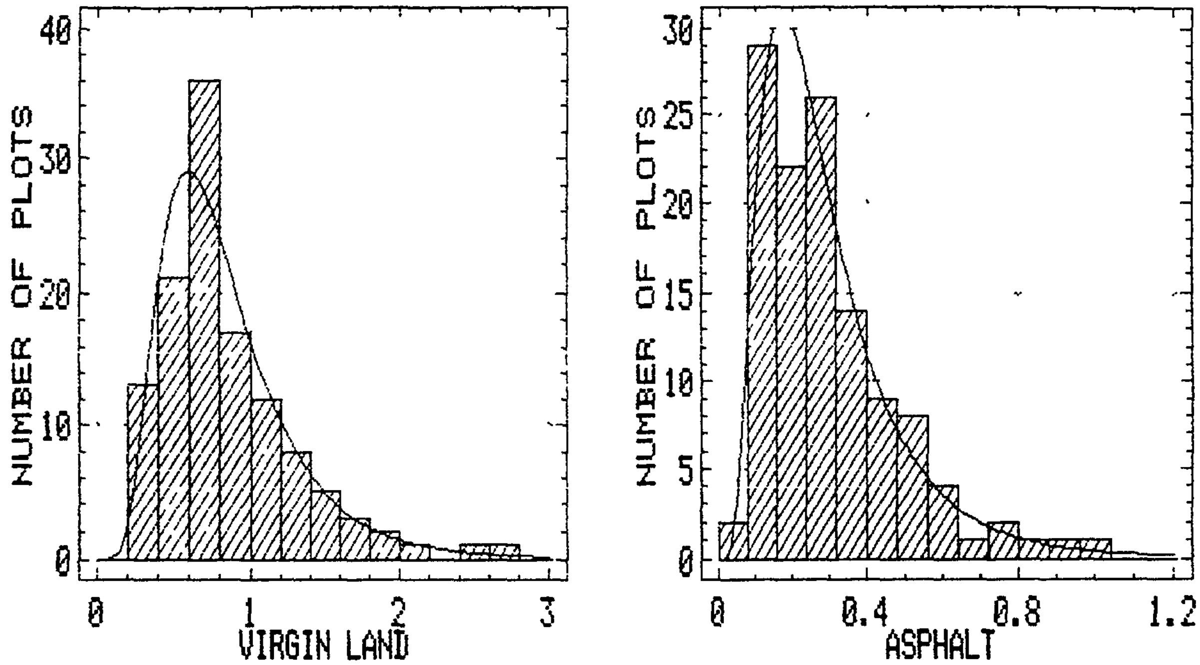


FIG 5 Distribution of Location Factors (rel units) in typical urban areas of the town Novozybkov

1 – undisturbed area, 2 – asphalt, 3 – wooden house [5], 4– multi-storey house [5]

years in inhabitants of separate villages reaches 110 mSv, and in critical groups (foresters, herdsmen) — 150-200 mSv. During this period the population has received 60-65% of the life-time dose of external gamma radiation. On the basis of results of wide-scale measurements of the radiation situation and poll of inhabitants on the mode of their behaviour, a stochastic model of forming the dose of external exposure in different groups of population of the contaminated area is being developed. The model will allow to predict dose distribution in critical groups of population and ground adequate measures of radiation protection.

REFERENCES

[1] IZRAEL, YU.A., VAKULOVSKII, S.M., VETROV, V.A., PETROV, V.N., ROVINSKII, F.YA., STUKIN, YE.D., Chernobyl: radioactive contamination of the environment, Leningrad, Gidrometeoizdat (1990) (in Russian).

[2] JACOB, P., MECKBACH, R., External exposure from deposited radionuclides, Proceedings of the seminar on methods and codes for assessing the off-site consequences of nuclear accidents, May 7-11, 1990, Athens (1990).

[3] GOLIKOV, V.YU., BALONOV, M.I., PONOMAREV, A.V., Estimation of external gamma radiation doses to the population after the Chernobyl accident, The Chernobyl Papers, Vol. I: Doses to the soviet population and early health effects studies, (MERWIN, S.E., BALONOV, M.I., Eds.), Research Enterprises (1993).

[4] ERKIN, V.G., LEBEDEV, O.V., Thermoluminescent dosemeter measurements of external doses to the population of the Bryansk region after the Chernobyl accident, The Chernobyl Papers, Vol. I: Doses to the soviet population and early health effects studies, (MERWIN, S.E., BALONOV, M.I., Eds.), Research Enterprises (1993).

[5] MILLER, K.M., KLUSEK, C.S., HUTTER, A.R., MONETTI, M., DAVIS, H.A., Measurements of external radiation and radioactivity in soil and air in Novozybkov, USSR, International Atomic Energy Agency, Vienna (1990).

EARLY MEASUREMENTS IN SCANDINAVIA FOLLOWING THE CHERNOBYL ACCIDENT

XA0054876

J. ROED, K.G. ANDERSSON
Risø National Laboratory,
Roskilde, Denmark

Abstract

EARLY MEASUREMENTS IN SCANDINAVIA FOLLOWING THE CHERNOBYL ACCIDENT.

The first cloud from the Chernobyl accident arrived over Scandinavia during the first days following the release. This gave a unique opportunity to study wet and dry deposition of different isotopes on various rural and urban surfaces, to model the wash-off, run-off and weathering processes from the early phase and to investigate the relationship between outdoor and indoor aerosol concentration. The information derived has had great importance for development of computer models to estimate the consequences of such accidental releases. Some of the data collected in the early period is compared to data obtained through recent experiments. A good agreement has been found between these sets of data.

1. INTRODUCTION

When the first cloud from the Chernobyl release reached the town Roskilde in Denmark on the 27th of April 1986, the weather was dry. In contrast, in Gävle in Sweden it rained heavily as the cloud passed. A plume from a later release passed over Denmark while it rained heavily. This presented a unique opportunity to study the behaviour of airborne radionuclides released to the atmosphere, including both dry and wet deposition.

Both forms of deposition are important in nuclear accident consequence assessment. The reason for this is that the external gamma dose due to deposited material can be a major contributor to acute effects [1)], and the dose from deposited long lived radionuclides is usually the major long-term hazard [2-4)]. In cases where the radioactive material is wet deposited, the effect of run-off can be important [5-9)]. Run-off water can carry away a fraction of the deposited radioactive matter through sewers, thus resulting in a less than 100% retention. Later on, some of the initially retained material can be removed by weathering [10-12)]. Further, the removal of radioactive matter by processes such as traffic and normal street cleaning must also be considered.

In risk assessment, it is extremely important to deal with contamination in the urban areas as this is where most of the population in the Western world lives. It is, however, not enough to know the total contamination in the urban area. The spatial distribution of the deposited material must also be known.

Deposition on indoor surfaces may also contribute significantly to the external exposure of the population.

2. DRY DEPOSITION

Dry deposition was studied in terms of dry deposition velocities on plastered walls, roof material, street concrete flagstone, asphalt, grass, trees and bushes. The measurements were made in Roskilde during the passage of the cloud. Throughout the deposition phase, the weather conditions were stable, the mean wind speed was $3 m{\bullet}s^{-1}$ at 8m height and the Pasquill stability was category B–C.

Table I shows the mean values of measured deposition velocities for different radioelements originating from the Chernobyl accident. The results of each single measurement have been given elsewhere[13)]. There was no obvious indication that the deposition velocity changed from one area to another, but it clearly differed for the various isotopes examined.

TABLE I. DRY DEPOSITION VELOCITIES OF VARIOUS RADIOELEMENTS (10^{-4} MS^{-1})

Isotope	**I***	**Cs**	**Ru**	**Ba**	**Ce**	**Zr**
Paved areas	4.6(9)	0.7(7)	3.5(9)	4.6(8)	8.1(9)	9.8(9)
Walls	3.0(4)	0.1(4)	0.4(4)	0.4(4)	0.9(4)	1.3(4)
Windows	2.3(1)	0.5(1)	0.1(1)	0.2(1)		0.1(1)
Grassed clipped	22 (1)	4.3(1)	4.1(1)	5.8(1)	7.7(1)	7.1(1)
Trees	80 (3)	7 (3)	25 (3)	26 (3)	39 (3)	45 (3)
Roofs	33 (3)	2.8(2)	3.4(3)	53 (3)	40 (1)	—

The figure in parenthesis represents the number of measurements made.
* elementary iodine

Particle bound caesium had the smallest value with a mean V_d of about $1{\bullet}10^{-4}$ m s^{-1}, and the highest V_d's of $10{\bullet}10^{-4}$ m s^{-1} were found for particulate cerium and zirconium.

The radionuclides may be divided into two groups, i.e. the volatile group to which I, Cs and Ru belong, and the refractory group which includes Ba, Ce and Zr. Aerosol samplings, mainly using low pressure cascade impactors, in different European countries following the Chernobyl accident [14-17)] have shown that these two groups had different particle sizes, that of the first being typically 0.4–1.0 μm compared with 2–4 μm for the second group. The lower deposition velocities which were recorded on grass and roofs for the particles from the first group agreed well with the observation that the larger particles have a higher deposition velocity. For paved areas, walls and trees the deposition velocity did not quite follow this pattern.

3. WET DEPOSITION

Precipitation scavenging or washout of particles and gases from the atmosphere can be significant contributors to ground deposition as was the case in Gävle more than 2000 km from Chernobyl [12)]. Run-off is a term used to describe the deposited rainwater which is not retained on the area receiving the rainfall. The following equation is valid for hard surfaces:

$$Q=P-I_a,$$

where Q is the direct run-off in mm, and I_a the initially accumulated rainfall. The amount of run-off from roofs is very sensitive to the construction material [5)]. A rainfall (P) of 9.2 mm shortly after the Chernobyl accident gave I_a values of 1.8 mm for cement tile, 4.2 mm for red clay tile, 1.4 mm for eternite (an asbestos type of material) and very nearly 0 mm for silicone treated surfaces. Later it was shown that on road surfaces I_a was 3.8 mm for asphalt and 3.4 mm for concrete.

Table II shows the concentration of different radionuclides in run-off water relative to that in rain water during a rainfall of 9.2 mm. Table III shows the amount of retained wet deposited matter on different types of roofs relative to deposition on a grassed area after a rainfall of 9.2 mm.

TABLE II. CONCENTRATION OF RADIOELEMENTS IN RUN-OFF WATER RELATIVE TO THAT IN RAINWATER FOR A PRECIPITATION OF 9.2 MM

	Isotope			
Surface	**Cs**	**I**	**Ru**	**Ra**
Cement tile	0.49	1.24	0.56	0.40
Red tile	0.55	1.05	0.65	0.58
Eternite	0.14	1.18	0.30	0.37
Silicone treated eternite	0.74	1.00	0.52	0.67

TABLE III. RELATIVE WET DEPOSITION ON DIFFERENT ROOFS

	Slope	^{137}**Cs**	^{134}**Cs**	^{131}**I**	^{106}**Ru**	^{103}**Ru**	^{140}**La**
Grassed area	0E	1	1	1	1	1	1
Cement tile	45E	0.58	0.62	0	0.42	0.27	0.68
Red tile	45E	0.68	0.71	0.43	0.60	0.53	0.69
Corrugated eternite	45E	0.87	0.88	0	0.65	0.64	0.68
Silicon treated eternite	45E	0.12	0.29	0	0.63	0.41	0.33
Corrugated eternite	30E	0.80	0.81	0	0.59	0.55	0.63
Silicon treated eternite	30E	0.18	0.25	0	0.49	0.47	0.22

Of the examined roof materials, only red clay tiles retained a measurable amount of Iodine. Only 20–35% of the caesium and the lanthanum on silicon treated roofs was retained, compared with 60–90% on other types of roof, while the retention of ruthenium was similar for all roof materials.

4. INDOOR DEPOSITION

Some results of a series of indoor deposition measurements following the Chernobyl release are shown in Table IV. The mean indoor deposition velocities were found to be of the same order of magnitude as those recorded outdoors on walls and horizontal pavements. These indoor deposition velocities have been compared with the results of recent experiments, in which porous silica particles of various monodisperse size distributions ranging from 0.5 to 5.5 µm and labelled with neutron activatable tracers were applied [18)].

The Chernobyl caesium aerosol was found to have a size distribution which peaked a bit below 1 :m, and atmospheric ^{7}Be is known to be associated with 0.5 to 1 µm particles. The mean indoor deposition velocity of the 0.5 µm silica particles has been found to be $0.61{\cdot}10^{-4}$ m/s in an unfurnished room and $0.82{\cdot}10^{-4}$ m/s in a furnished room, which agrees well with the values given in Table IV for the caesium and beryllium aerosols.

As for the refractory pollutants, such as cerium and zirconium, Chernobyl aerosol particle sizes in the range of 2–5 µm have been reported [14)]. As shown in Table IV, the mean indoor deposition velocity of these was found to range from $3 \cdot 10^{-4}$ to $5 \cdot 10^{-4}$ m/s. In comparison, the mean indoor deposition velocity of 4 µm silica particles has been measured to be $2.42 \cdot 10^{-4}$ m/s in an unfurnished room and $3.11 \cdot 10^{-4}$ m/s in a furnished room.

TABLE IV. INDOOR DEPOSITION VELOCITIES

Isotope	**®$_d$, mean deposition velocity (m.s^{-1})**
^{137}Cs	6.4 H 10^{-5}
^{134}Cs	6.2 H 10^{-5}
^{131}I (particulate)	1.1 H 10^{-4}
^{7}Be	7.1 H 10^{-5}
^{103}Ru	2.0 H 10^{-4}
^{106}Ru	1.7 H 10^{-4}
^{141}Ce	3.1 H 10^{-4}
^{144}Ce	3.9 H 10^{-4}
^{95}Zr	5.8 H 10^{-4}
^{95}Nb	1.9 H 10^{-4}

5. DISCUSSION AND CONCLUSION

A series of measurements of dry deposition including indoor assessments was performed during the Chernobyl accident. The results provided a good understanding of the spatial distribution of dry and wet deposited material. This has enabled us to model the essential processes concerning dose assessment, which leads to the ultimate goal: the formation of an emergency strategy for areas contaminated after a nuclear accident.

REFERENCES

[1] GESELLSCHAFT FÜR SICHERHEIT: DEUTSCHE RISIKOSTUDIE KERNKRAFTWERKE, Fachband 8, Unfallfolgenrechnung und Risikoergebnisse, Verlag TgV Rheinland, Köln, FRG (1981).

[2] UNITED NATIONS SCIENTIFIC COMMITTEE ON EFFECTS OF ATOMIC RADIATION. SOURCES, Effects and Risks of Ionising Radiation, 1988 Report to the General Assembly, United Nations, New York, USA (1988).

[3] GJØRUP, H.L., JENSEN, N.O., HEDEMANN JENSEN, P., KRISTENSEN, L., NIELSEN, O.J., PEDERSEN, E.L., PETERSEN, T., ROED, J., THYKIER NIELSEN, S., HEIKEL VINTER, F., WARMING, L., AARKROG, A., Radioactive contamination of Danish Territory after Core-melt Accident at the Barsebäck Power Plant, Risø-R–462, Risø National Laboratory, DK–4000 Roskilde (1982).

[4] KELLY G.N., The importance of urban environment for accident consequences, Radiat. Prot. Dosim. **21** (1987) 13–20

[5] ROED, J., Run-off from roof material following the Chernobyl accident, Radiat. Prot. Dosim. **21** (1987) 59–64.

[6] JACOB, P., MECKBACH, R., MÜLLER, H.M., Messung von Gammadosisleistungen durch künstliche Radionuklide in städtischer Umgebung, Proceedings 7, Fachgespräch zur Überwachung der Umweltradioaktivität, Der Reaktorunfall in Tschernobyl, Ergebnisse, Erfahrungen, Folgerungen, Neuherberg, 16-17. Nov. 1987, 29–35.

[7] Institut für Strahlenhygiene des Bundesamtes für Strahlenschutz, 8042 Neuherberg, FRG (1987).
[8] KARLBERG, O., Run-off and dry deposition of the Chernobyl fallout. Analysis of field gamma measurements in the Gävle and Studsvik areas, STUDSVIKINF-90/11, Studsvik Nuclear, 61182 Nyköping, Sverige (1990).
[9] JACOB, P., MECKBACH, R., MÜLLER, H.M., Reduction of external exposures from deposited radioactivity by run-off, weathering, street cleaning and migration in the soil, Radiat. Prot. Dosim. **21** (1987) 51–58.
[10] KARLBERG, O., Run-off and Retention of Chernobyl fall-out in Urban Areas (in Swedish), Fifth Nordic Radioecology Seminar in Rättvik, Sweden (1988).
[11] KARLBERG, O, Weathering and migration of Chernobyl fallout in Sweden, Radiat. Prot. Dosim. **21** (1987) 75–78.
[12] JACOB, P., MECKBACH, R., External Exposure from Airborne Radionuclides, Proceedings of the Seminar on Methods and Codes for Assessing of the Off-site Consequences of Nuclear Accidents, May 7-11, 1990, Athens (1990).
[13] ROED, J., SANDALLS, J., The Concentration Levels of Chernobyl Fallout on Different Surfaces in Gävle in Sweden, Proceedings of the XVth Regional Congress of IRPA on The RADIOECOLOGY of Natural and Artificial Radionuclides, FS-89-48T (1989) 1013–4506.
[14] ROED, J., Dry deposition in rural and urban areas, Radiat. Prot. Dosim. **21** (1987) 33–36
[15] RULIK, P., BUCINA, I., MALATOVA, I., Aerosol Particle Size Distribution in Dependence on the Type of Radionuclide after the Chernobyl Accident and in NPP, Proceedings of the XVth Regional Congress of IRPA on The RADIOECOLOGY of Natural and Artificial Radionuclides, FS-89-48T (1989) 1013–4506.
[16] REINEKING, A., BECKER, K.H., PORSTENDÖRFER, J., WICKE, A., Air Activity Concentrations and Particle Size Distributions of the Chernobyl Aerosol, Rad. Prot. Dos., Vol.19, No.3, (1987) 159–163.
[17] JOST, D.T., GÄGGELER, H.W., BALTENSPERGER, U., ZINDER, B., HALLER, P., Chernobyl Fallout in Size-fractionated Aerosol, Nature, Vol. 324, (1986) 22–23.
[18] TSCHIERSCH, J., GEORGI, B., Chernobyl Fallout Size Distribution in Urban Areas, J. Aerosol Sci., Vol. 18, No.6, (1987) 689–692.
LANGE, C., Protective Value of Houses: Indoor Deposition, Ph.D. thesis, Risø Natl. Lab., to be published (1994).

INTERCOMPARISON OF IODINE THYROID DOSES ESTIMATED FOR PEOPLE LIVING IN URBAN AND RURAL ENVIRONMENTS

G. VOIGT
GSF — Forschungszentrum für
Umwelt und Gesundheit,
Oberschleißheim, Germany

XA0054877

Abstract

INTERCOMPARISON OF IODINE THYROID DOSES ESTIMATED FOR PEOPLE LIVING IN URBAN AND RURAL ENVIRONMENTS.

The radioecological model ECOSYS, developed in GSF–Institut für Strahlenschutz has been applied to calculate thyroid doses to the population due to I-131 exposures after the Chernobyl accident. The main contribution to the thyroid doses calculated is given by the consumption of milk and vegetables. Results are presented taking into account the different activity concentrations measured in milk of private family cows and mixed collective milk of a creamery in upper Bavaria, as well as different consumption behaviour of children and adults in rural and urban areas. Thyroid doses due to different milk consumption habits and a different milk origin in adults living in urban environments are estimated to be up to 12 times, in children up to 3 times lower than those estimated for rural environments. The dose contribution by vegetables, however, in any case exceeded the one by milk because of the high intake rates for the case investigated here. These values, however, may be overestimates for vegetables and have a very high uncertainty. For adults total thyroid dose by ingestion was higher in rural areas by a factor of 1.4, for children at the age of 10 years, total thyroid dose by ingestion was 1.5 times higher in urban environments for the conditions described here.

1. INTRODUCTION

After the Chernobyl accident many measurements of environmental and food samples were performed in order to validate and improve the radioecological model ECOSYS (Müller and Pröhl 1993) developed at the GSF–Institut für Strahlenschutz. Additionally experiments were performed to get realistic information about the environmental behaviour of the deposited radionuclides, a summary of these results is given in Jacob et al. 1993. One of the most important radionuclides is I-131, because of its ability to concentrate in the thyroid and result in high organ doses. Especially in the highly radiosensitive thyroids of children the uptake of radioiodine results may lead to the development of thyroid cancer or thyroid diseases.

The increasing thyroid cancer cases following the years after the Chernobyl accident reported for Belarus and Ukraine, and recently for Russia have focused the interest on the reconstruction of the doses not only for the affected children but also for the population exposed to radioiodine.

The thyroid doses due to inhalation and ingestion as one of the main contributions to the total dose can be estimated in ECOSYS-87 for the different age-groups if information about the deposition (dry, wet, air concentration, time of season), the composition of the fallout (aerosol, organic and elemental), or better if activity measurements in milk and vegetables, the main contributors to the ingestion dose, are available. Especially the consumption behaviour of the population (self-suppliers or non-self-suppliers representing people living in rural and urban environments) has to be considered. In this presentation different consumption rates and measured activities in farm and creamery milk have been taken into account in order to estimate I-131 thyroid doses after the Chernobyl fallout for adults and children aged 10 living in South Bavaria, and to compare the resulting doses for urban and rural populations corresponding to non self- and self-suppliers.

2. MATERIALS AND METHODS

The model ECOSYS-87 used for the calculations is described in detail in Müller and Pröhl (1993). A deposition scenario was chosen according to the Chernobyl fallout on 1st of May in Bavaria: deposition on soil 100 kBq with 15 % dry deposition and 85 % with 5 mm rain, ratio of aerosol:elementary:organic iodine=0.25:0.25:0.50 (values measured in Munich–Neuherberg). I-131 activity concentrations in milk were introduced by the results of measurements performed at a Bavarian dairy farm and a Bavarian creamery (Fig. 1).

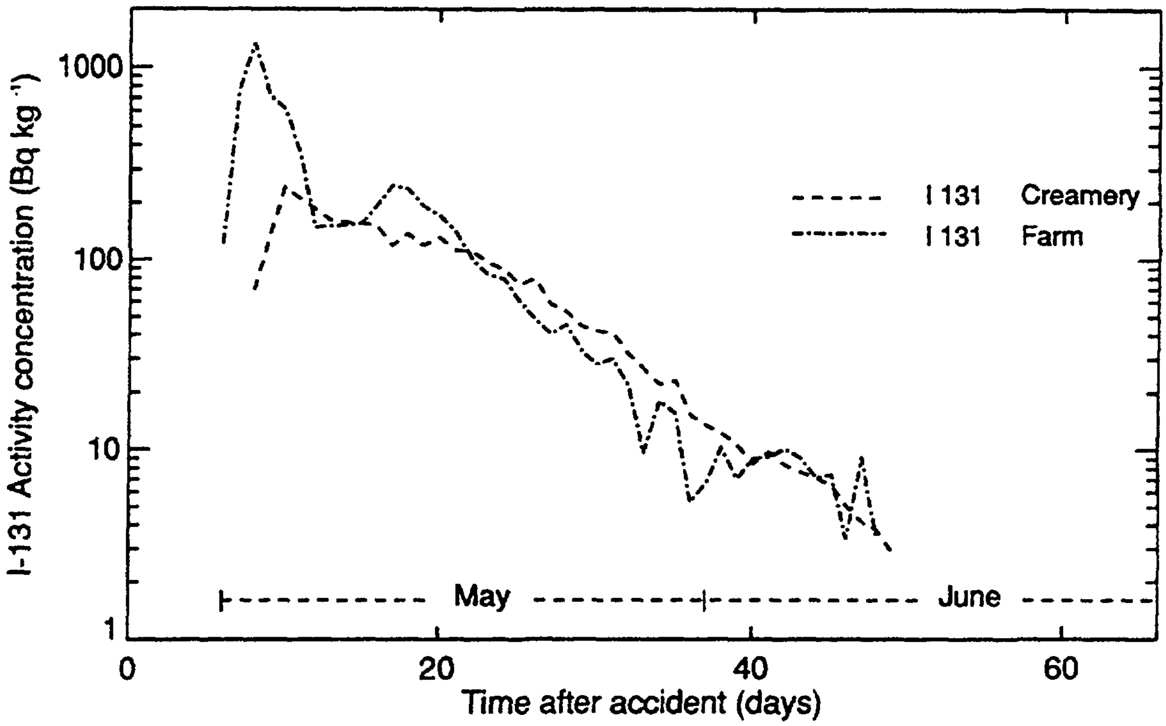


FIG. 1. I-131 activity concentrations in milk in Southern Bavarian measured at a private farm and a commercial creamery

Milk and vegetable consumption rates for adult and juvenile (aged between 4 to 14) self-suppliers (S = rural) and non selfsuppliers (NS = urban) were taken from Burkhardt (1988) and are given in Table I. This information was achieved during February/March and May 1987 in a Southern Bavarian population when individuals were asked to collect an identical amount and composition of their food.

TABLE I. MILK AND VEGETABLE CONSUMPTION OF RURAL AND URBAN POPULATION (BURKHARDT, 1988)

Location	Individuals	Milk (g/d)	Vegetables (g/d)
Rural (S)	Adults: 9 (4 male, 5 female)	400	620
	Children 3 (1 male, 2 female)	200	370
Urban(NS)	Adults 5 (1 male, 4 female)	100	420
	Children 3 (1 male, 2 female)	350	210

3. RESULTS AND CONCLUSIONS

The estimated thyroid doses due to milk consumption for adults and 10 year old children in urban and rural environments are given in Fig. 2. For adults organ doses were higher by a factor of 12 for rural and urban environments, for children this factor was 2.6. Difference in integrated activity concentrations for May 86 in milk of an individual farm and the collective milk was about a factor of 3 with higher values in farm milk. The additional factor of 4 in adults resulted from the higher milk consumption of rural inhabitants. This difference was not expressed that high in children where milk consumption was not too different, i.e. even less in rural children. The thyroid doses between adult and juvenile consumers due to milk uptake was 1.4 and 9 times (rural and urban, respectively) higher in children.

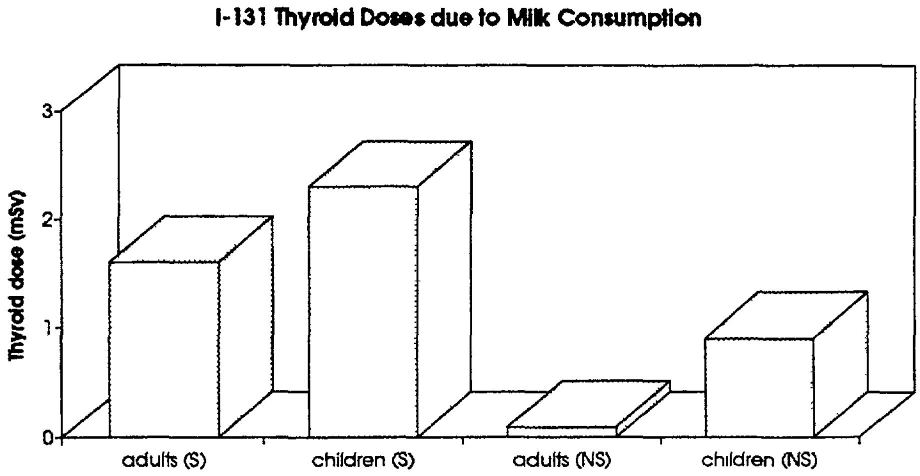


FIG. 2. Estimated thyroid doses due to milk consumption to adults and children.

The total thyroid dose due to ingestion of vegetables and milk is presented in Fig. 3 for adults and in Fig. 4 for children. For adults and 10 year old children in rural environments it was approximately equal, in urban environments juvenile doses pointed out to be 2.3 times higher for children. This difference will be more expressed for children of younger ages due to higher dose conversion factors and higher milk consumption rates.

In rural environments total ingestion doses to the thyroid for adults were found to be 15 times higher for selfsuppliers, for children thyroid doses were 4.4 times higher, respectively. This difference is a result of the assumptions made:

a) for rural environments activity concentration in vegetables are based on only locally produced plants grown in open areas. This is the worst case assumption and may represent an overestimation. Especially in these mountain areas vegetables are grown at this time of the year in green houses or covered containers preventing it from direct contamination.

b) for urban environments, a dilution of vegetable activities by imported non contaminated food is assumed; only 10% locally and in open areas produced vegetables are taken into consideration for calculating the thyroid doses due to fresh vegetable intake.

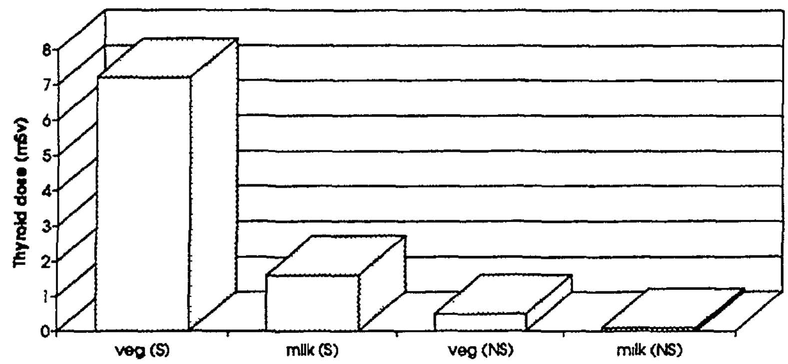


FIG. 3. Estimated thyroid doses due to vegetables and milk to adults.

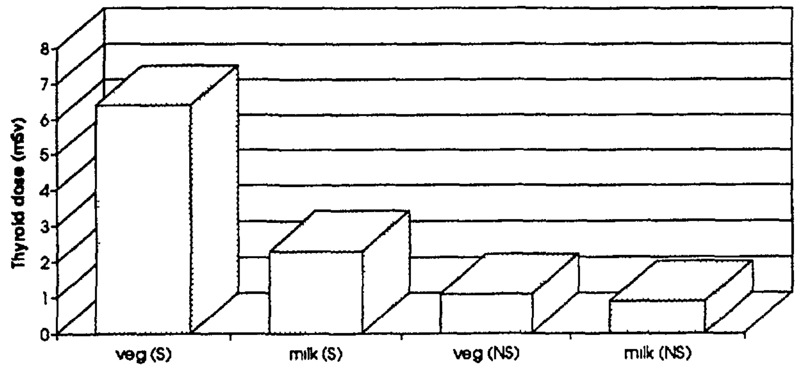


FIG. 4. Estimated thyroid doses due to vegetables and milk to children (10(.

For general conclusions, milk and fresh vegetable intake may vary considerably between individuals; here only a rough estimate resulting from 3 and 9 individuals each could be considered. Doses due to milk consumption is available. However, more precise dose estimates for self and non selfsuppliers cannot be drawn because no information about dilution of activities by imported uncontaminated goods, and representing supermarket supply, is available. The value of 10% local products may represent a best estimate in this case for non selfsupplying people. Other high uncertainties are given by rather inaccurate knowledge of the local start of the vegetation period within a short time scale (days). Therefore also accurate knowledge about the vegetation status of fresh vegetables during the exposure time is important for reliable dose estimates. In dependence of the time of season fresh vegetable consumption may have a significant influence when thyroid doses have to be reconstructed especially for selfsupplying population groups.

REFERENCES

[1] BURKHARDT, J., Ingestion von Radiocaesium und Strontium 90 bei Selbst- und Fremdversorgern im 1. Folgejahr nach dem Reaktorunfall von Tschernobyl als Grundlage für die Ableitung sekundärer Eingreifrichtlinien, Schriftenreihe Reaktorsicherheit und Strahlenschutz, BMU–1988–196 (1988) 11–20.

[2] MÜLLER, H., PRÖHL, G., ECOSYS–87: A dynamic model for assessing radiological consequences of nuclear accidents, Health Phys., **64** (1993) 232–252.

[3] JACOB, P., MÜLLER, H., PRÖHL, G., VOIGT, G., BERG, D., PARETZKE, H.G., REGULLA, D., Environmental behaviour of radionuclides deposited after the reactor accident of Chernobyl and related exposures, Radiat Environ Biophys., **32** (1993) 193–207.

EMERGENCY RESPONSE PLAN FOR ACCIDENTS IN SAUDI ARABIA

K.M. AL-SOLAIMAN, A.M. AL-ARFAJ, M.A. FAROUK
Institute of Atomic Energy Research,
King Abdulaziz City for Science and Technology,
Riyadh, Saudi Arabia

XA0054878

Abstract

EMERGENCY RESPONSE PLAN FOR ACCIDENTS IN SAUDI ARABIA.

This paper presents a brief description of the general emergency plan for accidents involving radioactive materials in the Kingdom of Saudi Arabia. Uses of radioactive materials and radiation sources and their associated potential accident are specified. Most general accident scenarios of various levels have been determined. Protective measures have been specified to reduce individual and collective doses arising during accident situations.

Intervention levels for temporary exposure situations, as established in the IAEA's basic safety standards for protection against ionising radiation and for the safety of radiation sources, are adopted as national intervention levels. General procedures for implementation of the response plan, including notification and radiological monitoring instrumentation and equipment, are described and radiation monitoring teams are nominated. Training programs for the different parties which may be called upon to respond are studied and will be started.

1. SOURCES OF HAZARDS AND POTENTIAL ACCIDENTS

Radioactive materials are manufactured, exported, imported, transported and used in industry, medicine, research and teaching in the Kingdom of Saudi Arabia. Some radioisotopes and radiopharmaceuticals are produced at the research center of the King Faisal Specialist Hospital at Riyadh using a 28 MeV variable energy cyclotron. Some of these radioisotopes are used locally and some are exported abroad. Moreover, different radiation sources are imported from abroad and are widely used in different techniques. The main techniques involving the use of radioactive sources in the Kingdom, together with the maximum activity used by a single user, are summarised in Table I. All possible accident scenarios with different radiation sources can be grouped as follows:

(1) Human or technical errors that may lead to a situation where the radioactive source becomes unshielded and it becomes impossible to retract it into its containe
(2) A transport accident involving radioactive sources or material which leads to a situation where the radioactive source becomes unshielded or to spillage of the radioactive material and its dispersion.
(3) Conventional fire or explosion in which the container and shield of source may melt and consequently the source becomes unshielded, and spillage of radioactive material and dispersion may occur.
(4) A radioactive source may be misplaced, lost or stolen, or it may have ended up in the possession of those who are unaware and may interfere with it.
(5) A spillage of a radioactive material due to a human or a technical error, causing contamination inside an installation which also may extend to off-site.

The aforementioned scenarios of accidents involving radiation sources and materials may be grouped into three characteristic groups as follows:

Loss of the radioactive source shielding, leading to external exposure of the workers, as well as of the general public.

(1) Loss of containment of the radioactive material, leading to its spillage, dispersion and contamination of people and environment in on-site locations with a possibility of extending to the off-site locations.
(2) Loss or theft of a source or a radioactive material, leading to contamination of people and the environment.

For the purpose of this emergency plan, radiological accidents are classified according to the geographical extent of the consequences as follows:

I. Level 1: Consequences of the accident are limited to a single room or building.
II. Level 2: Consequences of the accident are limited to the perimeter of the installation.
III. Level 3: Consequences of the accident are of significance outside the installation.

2. THE EMERGENCY RESPONSE PLAN

2.1. Objectives of the Plan

The objectives of responding to emergency situations depend to a large extent on the accident type. However, since the emergency response plan should have an adequate degree of flexibility to cope with accidents of different natures and different levels of severity, the common objectives for different emergency situations should be outlined. When responding to accidents of the first group, the objectives should be as follows: Keeping individual and public doses as low as reasonably achievable by introducing the proper protective measures, assessing the doses accurately, arranging for medical assistance of the injured personnel, if there are any and restoring control over the source, by returning it inside its shield or placing it in a safe shielded position. When responding to accidents of the second group, accidents caused by loss of the containment of a radioactive material, the objectives of the response are as follows: Keeping the doses as low as reasonably achievable, controlling, contamination and keeping the contaminated areas as low as possible, assessing the contamination levels and doses, arranging for medical assistance and decontamination of injured personnel, if any, decontamination and clean-up of the contaminated objects, collecting and disposing of the radioactive waste. Accidents caused by misplacement, loss or stealing of the radioactive source, the objectives of the response are as follows: Locating the source, effecting the recovery of the source and bringing it under control, keeping doses as low as practically possible, assessing doses accurately, arranging for medical assistance of injured personnel, if any.

2.2. Time scale and phases of the accidents

Radiological accidents involving radioactive materials and sources may last minutes or a few hours and severe ones might continue for several days. Nevertheless, in all circumstances three distinct phases may be identified; these are the recognition phase, initial phase and the recovery phase. The recognition phase starts from the moment loss of control over the source takes place until the recognition that an accident has occurred. The initial phase is the time between the moment of recognition of the accident until exposure to the source has been brought to a certain degree of control, but before restoration of the situation is normal.

The immediate steps for responding to the emergency, after the recognition phase, depend on the accident type. In case of loss of shielding, the accident is considered under a certain degree of control once people are evacuated from the high dose rate area, and the initial phase is terminated. In the case of a contamination accident, the initial phase is over when the spreading of the radioactive contamination is stopped. In the case or theft of a radioactive source the initial phase ends when the source has been found or located. The recovery phase is the period between achieving a certain degree of control over the source up to the moment of reinstatement of normal conditions. Restoration of the situation to normal conditions during the recovery phase is considered urgent in cases where the effects of the accident involve people or areas outside the facility, but in cases where these effects are confined, restoration should be carried out only after detailed planning.

2.3. Responsibilities and Responding Organization

(1) **The Licensee:** The licensee has the primary responsibility for the safe use and control of the licensed radioactive materials and sources. It is his responsibility to prepare detailed response plans to all credible scenarios of accidents that can be anticipated with the licensed sources and materials. These plans should include parts dealing with identification of accidents, immediate steps needed to control exposures, assessments, protective actions, notifications of the local Civil Defence authorities and the competent radiological authority.

(2) **The Consignor and the Carrier:** In transport accidents, although the consignor has the primary responsibility, the carrier also bears safety responsibilities during transport. The consignor is responsible for complying with the national regulations related to the transport of radioactive materials. He should supply the carrier with all appropriate emergency instructions and schedules, be ready to offer all needed assistance in an emergency involving the consignment, and send emergency crews to the accident site if needed. The carrier is responsible for complying with the national regulations, being informed of different response procedures along the route, and getting the proper emergency instructions on board the vehicle.

(3) **The Local Authorities:** The intervening local civil defence authorities (police, fire brigade, ambulance and medical services) have the responsibility to protect the public. These authorities should rely on their general procedures and normal methods of operations supplemented with specific advice and recommendations given to them when notified of the accident. The licensee must be prepared to give advice and instructions to the local defence personnel.

(4) **The Competent Authority:** King Abdulaziz City for Science and Technology (KACST) is the National Competent Authority in the Kingdom of Saudi Arabia. The Institute of Atomic Energy Research (IAER) being the arm of KACST is responsible for discharging the day to day functions. KACST is responsible for the approval, review and periodic test of the emergency response plans prepared by the licensees and for ensuring the preparedness of these plans. It should be notified about all types of accidents to assess all undertaken protective actions, and to offer the needed assistance for all on-site accidents. For all accidents having off-site consequences KACST should be notified by the licensee immediately to take the off-site assessments and to ensure compliance of the licensee in mitigating the consequences. KACST is prepared to respond to accidents of different levels through communication and notification systems, equipping of radiological monitoring teams with adequate instruments and equipment's, as well as a decontamination team. It carries the necessary training to immediately respond to different types of accidents.

2.4. Communication and Notification

(1) Access to the KACST has been made available at any time. Capability to receive notifications and reports from licensees and users has been secured through four telephone lines, two of them are connected to the Director of the Institute of Atomic Energy Research (IAER) (one at day time and the other at night) and the other two are connected to the head of the radiation protection department of IAER. The licensee, user, radiation protection officer

(RSO) or qualified expert should immediately notify the IAER of the fact an emergency situation exists, unless the accident is considered a minor one. In the later case, a detailed report should be sent to IAER. In general, the accidents which are considered minor ones have been defined for all licensees.

(2) The notification should be done accurately and in accordance with the form defined in the national basic safety standard, and should include complete information on notified, accident, sources, and injuries.

(3) When the emergency situation is terminated, a written report should be provided to IAER. It should include detailed information and reasons of the accident, response procedures and methods, all assessments of exposure among occupational workers and the general public, and all corrective actions to avoid repetition of the accident.

2.5. Control of Access

Control of access to hazardous areas depends on the type of accident and its magnitude. In the case when a source is missed or stolen, control of access is not applicable. However, in the case of loss of shielding, contamination or transport accidents it is a must. The limits of the restricted areas depend on nature and activity of the exposed source, degree of release or contamination, and on weather and wind direction. These limits should be defined immediately after the occurrence of the accident by the operator. The RSO should define the limits of the restricted areas so that the exposure outside them is normal after careful assessment of the situation. The Competent Authority should evaluate the extent of the restricted area. Control of access will be carried out using physical barriers (walls, doors, windows), affixing warning labels and signs, stopping local ventilation and air conditioning system since they may affect dispersion of radioactive material, using civil defence or traffic barriers, and cordoning the area by police brigades. Access to cordoned areas will be made only through a check point which should be used as a radiological control station for people, equipment and material and as an assembly point for responding and for emergency crews.

2.6. Equipment and Emergency Teams

During all stages of management of the accident, radiation measuring instruments are required. The user should have only those instruments that are necessary for his own specific source or material, while the competent authority has all instruments that may be necessary to respond and monitor radiation or contamination in all situations. Sets of different personnel dosimeters are maintained, calibrated and regularly checked and are ready for use at any time. A set of survey meters, radiation and contamination monitors, needed for an appropriate response to different accidents, radiation, energy ranges and radiation intensities, are maintained in good working condition. Moreover, a mobile intervention laboratory provided with radiological monitoring instruments, sampling equipment and other accessories is ready to respond to any emergency situation. This laboratory (8.0 x 2.2 x 2.1 m. vehicle) contains a whole body scanner based on a hyper-pure germanium spectrometer, a high resolution germanium spectrometer with the associated electronics, computer and software, and a proper lead shield, separate counting facilities for alpha and beta gross counting and NaI (Tl) gamma-ray spectrometer with the associated electronics and lead shield.

At present there are two teams (3 members each) engaged in the emergency response plan. They are all working in the IAER and have good experience in radiation and spectroscopic measurements, and they are headed by an experienced senior nuclear physicist. Soon a third team will be prepared to meet the requirements for covering 24 hour monitoring. A decontamination group headed by a senior radiochemist is also ready to carry out any decontamination activities and to give needed advice to users or to the Civil Defence personnel in this matter.

2.7. Medical Care

Severe accidents may result in external doses which exceed thresholds for the deterministic effects of radiation. For that case, it has been arranged that King Faisal Specialist Hospital and Research Center at Riyadh (Capital of KSA), where medical practitioners with some experience in radiation effects are available, will be responsible for the medical treatment of radiologically injured individuals. In case of internal exposure, it is now being discussed with the hospital to prepare the special facilities, equipment, materials and expertise to cope with personnel decontamination and to limit the spread of contamination.

TABLE I. TECHNIQUES INVOLVING THE USE OF RADIOACTIVE SOURCES IN SAUDI ARABIA TOGETHER WITH MAXIMUM ACTIVITY USED BY A SINGLE USER

No.	Used technique and sources	Max. Activity
1.	**Radiography techniques (industrial non-destructive testing)**	
	Ir-192	250 Ci
	Co-60	30 Ci
	Cs-137	30 Ci
	Neutron sources -(Am+Be) and Cf-252	-<1 Ci
	Beta radiography	-<1 Ci
2.	**Gauging techniques Transmission gauges ,Backscattering gauges**	
	Level gauge (gamma)	-<1 Ci
	Neutron thermalization (humidity measurement)	-<1 Ci
	Neutron transmission	-<1 Ci
3.	**Irradiation techniques**	
	Radiation beam therapy	14 kCi
	Brachytherapy	
	Radiation sterilization (Co-60)	250 kCi
	Polymerization (Co-60)	24 kCi
	Blood sterilization (Cs-137)	1403 Ci
	Research	24 kCi
4.	**Techniques involving unsealed radioactive materials**	
	Isotope production (^{99m}Tc, ^{125}I, ^{131}I...)	1 Ci
	Medical applications and diagnostic use	-<1 Ci
	Tracer techniques	-<1 Ci

2.8. Training

A training program is now planned for all personnel and bodies that will participate in the emergency response. The training program will include general radiation protection, radiation measurements and dose evaluation, use of different equipment and devices for radiological assessment, emergency procedures, organizations, communications and responsibilities.

The training program for the IAER personnel will take into consideration the roles that its personnel must play in responding to accidents. It will include accident assessment techniques, implementation of protective measures, and use of protective clothing. Moreover, users of radioactive materials and sources are instructed to provide training for their personnel in accordance with the potential hazards of the materials they are using.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Basic Safety Standards for Radiation Protection, Safety Series No. 9, IAEA (1982).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Derived International Levels in Radiological Emergency, Safety Series No. 81, IAEA (1986).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Emergency Planning and Preparedness for Accidents involving Radioactive Materials, Safety Series No. 91, IAEA (1989).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Recommendations for the Safe Use and Regulation of Radiation Sources, Safety Series No. 102, IAEA (1990).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, The Utilisation of Real Time Models as a Decision Aid, TECDOC-733, IAEA (1994).

PRE-PLANNED VERSUS UNPLANNED DECISION MAKING IN THE CASE OF ENVIRONMENTAL DECONTAMINATION

A.S. PASCHOA
Pontifícia Universidade Católica do Rio de Janeiro,
Departamento de Física

XA0054879

A. TRANJAN FILHO
Comissão Nacional de Energia Nuclear

Rio de Janeiro, Brazil

Abstract

PRE-PLANNED VERSUS UNPLANNED DECISION MAKING IN THE CASE OF ENVIRONMENTAL DECONTAMINATION.

Until a few years ago it was not usual to pre-plan realistic countermeasures directly related to a radiological emergency or a nuclear accident (RENA), mostly because the probability of occurrence of such events was considered to be too low for real concern. The Three Mile Island, Chernobyl and Goiânia accidents, however, changed long accepted views of the decision making community throughout the world. Today, meetings are being held just to discuss how one can go about making decisions to face the problems that may occur in a number of RENAs. The present work will examine several well established scientifically based radiological criteria to be used in decision making processes concerning either radioactive decontamination following a severe RENA, or decommissioning procedures. Such criteria can certainly be used to select pre-planned countermeasures, but can also be helpful as guidance to decision makers when facing a choice of untested and unplanned options. Selected advantages and disadvantages of each criterion based option will be presented and briefly discussed, as, for example, the amount of radioactive waste produced vis-B-vis the risk (concentration or projected dose) level adopted in the decontamination procedures. In addition, non-scientific aspects will be brought into the discussion, because their social, economical, and political implications cannot be ignored by responsible decision makers. Uncertainties associated with both non-scientific aspects and scientifically based environmental and dosimetric models will also be examined for specific cases.

1. INTRODUCTION

There are a variety of criteria that can be used to guide a decontamination procedure or even to decommission a site. However, it is fully recognised today that one should develop radiological criteria with well established scientific basis to be adopted in case of accidents. In the past, meagre attention was given to early preparation to deal with severe radiological emergencies and nuclear accidents (RENAs), because of widespread conviction that such RENAs were unlikely to occur. Mathematical exercises were carried out to prove that the probability of occurrence for any severe RENA was very low. The Three Mile Island, Chernobyl and Goiânia accidents, however, compelled decision makers to review their convictions, mostly because the perception of risk by the public did not coincide with the quantitative risk estimates obtained in mathematical exercises. Furthermore, practical considerations cannot usually be ignored because of political, social, psychological and economical implications that are subjacent to severe RENAs.

Technical aspects, per se, should also be examined with extremely great care because they can modify considerably the results obtained with environmental and dosimetric models in which pre-planned decisions can be taken. Thus, for example, parameters describing the retention of a particular radionuclide in the vegetation, the resuspension factor, or the time integral used in the models may have significant impact in the numerical results, affecting, ipso facto, the decision making process.

Several options can be considered preliminary to discuss the formation of radiological criteria to be used in decontamination procedures. As a starting point one can consider the following:

- Risk limitation by establishing limit values of concentrations or doses above which the risks to the public are deemed to be unacceptable;
- to select as a goal a risk so low that even if it cannot be achieved, due to practical considerations, by reaching a level close enough the risk for the public can be considered perfectly tolerable;
- to use the best available technology and to make the best effort in the decontamination procedures;
- to continue the decontamination procedures until return to the natural radiation background; and
- a mixture of all options mentioned above depending on practical considerations and not necessarily radiological criteria.

One should understand, however, that there are no universal criterion, because the criteria to be adopted will depend on the type, magnitude and severity of the RENA under consideration.

2. ADVANTAGES AND DISADVANTAGES

It is important to bear in mind that any option incurs advantages and disadvantages which are inherent to its adoption. In so being, the national authority responsible for the decontamination process should carefully analyse each option previous to adoption. Although what follows is not claimed to be a comprehensive analysis of each option, the discussion of some of the advantages and disadvantages may be helpful to the decision making process in the case of a severe RENA.

2.1. Risk limitation

2.1.1. Advantages

Risk limitation can be based on environmental and dosimetric models relatively well accepted by the radiological protection community, and can be defensible from the scientific viewpoint.

2.1.2. Disadvantages

The concept of quantitative risk is not easily accepted by the general public, making this option difficult to defend in public hearings. Thus, when one is presenting to the public concepts like acceptable or unacceptable risk, it is of little value to compare risks in the order of 10^{-2} (1/100), 10^{-4} (1/10,000) or 10^{-6} (1/1,000,000) associated with different human activities. Nuclear and non-nuclear accidents, like Three Mile Island, Bophal, Challenger, Chernobyl, and Goiânia made the public perception of risk estimates become similar to their perception of science fiction. As a matter of fact, the general public became so confused with the low probability of occurrence of severe accidents with self proclaimed accident free technologies, that they rather prefer to believe in subjective information than in scientific knowledge. Horoscopes, astrological maps and hand reading are examples of non-scientific and non-quantitative perceptions widely accepted by the general public. Even for a significant segment of the community of liberal professionals and scholars, not directly involved with the nuclear sciences, risk perception concerning nuclear accidents does not coincide with that of the nuclear community.

2.2. Very low risk

2.2.1. Advantages

This option avoids the usual discussion that the adopted risk limit is not low enough. It is usually defensible in debates with the scientific community.

2.2.2. Disadvantages

The cost to reach or get close to the low risk goal can easily become prohibitively high. In addition, the absence of a well established and achievable risk limit may imply in the production of an unjustifiable high volume of low level radioactive wastes. As a consequence, the future waste management may become too costly.

2.3. Best technology available

2.3.1. Advantages

It is obvious that if the best technology is timely and easily available it will be used. Thus, it depends on the site and circumstances of the RENA. However, it is important not to postpone the decontamination procedures until the best technology becomes available, to avoid scattering the initial contamination. So, whenever the best technology and the best trained individuals are available this option presents real advantages.

2.3.2. Disadvantages

The best technology or the best individuals to operate the devices and machinery may not be available. The problem of cost should also be taken into proper consideration to avoid unnecessary high decontamination costs in a minor accident.

2.4. Return to radiation background

2.4.1. Advantages

Whenever possible this is the ideal option. It is easily defensible in debates with either the scientific community or the general public.

2.4.2. Disadvantages

It is not always possible to return to the original radiation background. In addition, it is necessary to know the baseline before the accident in order to convince the critics that the background was reached. This is particularly true when one is dealing with accidents involving naturally occurring radionuclides or decommissioning technically enhanced sites.

2.5. Mixture of all options

2.5.1. Advantages

Different criteria can be applied to different problems that occur in decontamination. A selection of an option may depend on the importance of the site or entity to be decontaminated.

2.5.2. Disadvantages

One can be accused of lack of consistency when dealing with different problems. It is not easy to convince scientists and the public that different criteria may be applicable to different problems.

3. PRE-PLANNED CASE STUDY

Although there are a number of pre-planned studies reported in the open literature, one should bear in mind that a RENA seldom occurs in a predicted way.

In the case of nuclear power plants case studies are not only discussed in the licensing procedures, but are also updated as new information become available. As one among many examples, one can mention the United States Nuclear Regulatory Commission (USNRC) revision on safety systems response to loss of coolant and loss of off-site power (1).

4. UNPLANNED CASE STUDY — GOIÂNIA

4.1. Accident characterisation

The Goiânia accident has been fully described and characterised in a series of publications (2–4), however, many known interesting aspects, some of them relevant to decision making remain unpublished (5,6). This workshop may bring to light some new aspects concerning the characterisation of the Goiânia accident.

4.2. Source term characterisation

The source term was a broken teletherapy capsule of $^{137}CsCI$ with an initial activity of about 59TBq (1375 Ci) (3,4,7). The overall activity recovered in the decontamination procedures, including the remnants of the broken capsule, was estimated to be 49.0 ± 1.7 TBq (1324 ± 51 Ci). The uncertainty reported here represents about 3%, and it is an estimate based on data and information gathered and recorded by the teams involved in recovering the wastes resulted from the decontamination procedures at the time of the accident.

4.3. Control systems

One important aspect to delimit an accident to its initial and unavoidable consequences is to be able to act promptly. Unfortunately, this was not the case in Goiânia. Almost two weeks had elapsed before the accident was discovered mostly due to an unbelievable mixture of common sense and luck. After the discovery of the accident, the actions taken were able to control the already extensive damage to persons and properties.

Today, many things could be said as how one would go about in dealing with the Goiânia accident when it was first discovered. However, the responsibility to make a decision at the right time is something quite different than comment on that decision "a posteriori".

4.4. Decision on decontamination

In the case of Goiânia, one could say that the decision on decontamination had components of several criteria. Thus, a mixture of options can better describe the decision making process on the decontamination of Goiânia.

Reference levels were suggested to be used in the case of the Goiânia accident (3). Figure 1 represents schematically the reference levels with the variation of the natural radiation background in Brazil. The cut off level was to be chosen somewhere between the investigation and the action levels, taking into account the high variation of the natural background. The levels shown in Figure 1 were based on a relative scale, which in turn was reached based on the level of deposition of ^{137}Cs on the soil and the corresponding exposure rate (3,8-11). One of the objectives of the suggested reference levels was to reduce the amount of very low and non-radioactive wastes produced. However, one must again bear in mind that the responsibility for the final decision is different than that involved in making suggestions. The scientific subsidy is quite important for decision makers, but there are many other factors that have to be taken into account by responsible decision makers.

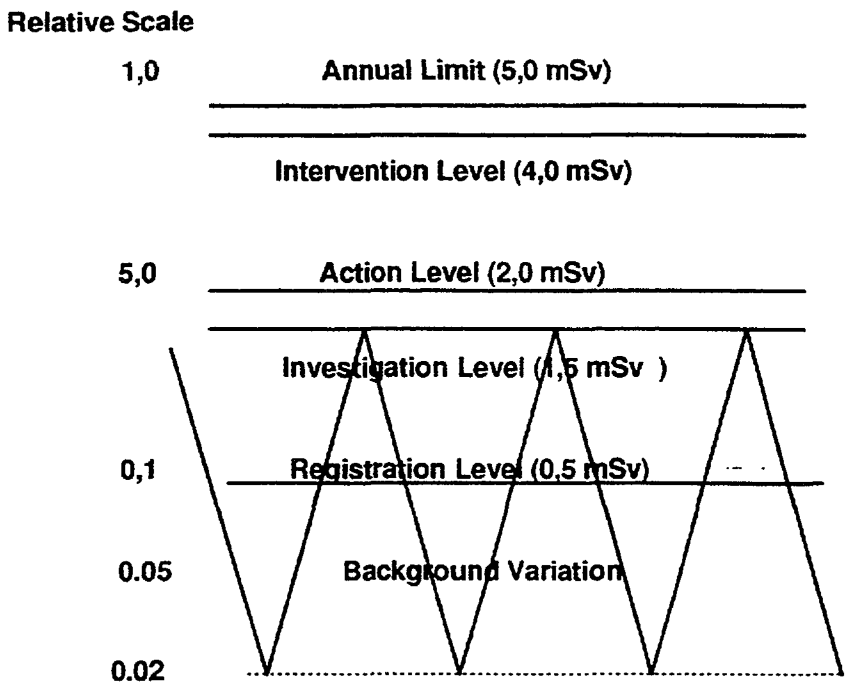


Fig. 1. Reference levels for Goiânia

5. CONCLUDING REMARKS

– Preliminary options to discuss the formation of radiological criteria to be used in decontamination procedures were presented and briefly discussed critically.

- Although one can pre-plan for an accident, the actual cases are mostly unpredictable. However, emergency preparedness should be maintained, because it is helpful even in unplanned cases.
- The Goiânia accident was briefly reviewed as an example of an unplanned case study.
- It was observed that in Goiânia a mixture of options in the decision making process occurred.
- Last, but not least, one concludes that the final decisions should be well subsidised scientifically, however, the responsibility remains with the authority who has the ultimate legal obligation to take decisions.

REFERENCES

[1] UNITED STATES NUCLEAR REGULATORY COMMISSION (USNRC), Safety Systems Response to Loss of Coolant and Loss of Offsite Power, NRC Information Notice 93-17, Revision 1, (1994) 4 pp.

[2] ALVES, R.N., Relatório sobre o Acidente Radiológico de Goiânia, presented at the Brazilian Parliamentary Commission on the Accident of Goiânia, 10 March 1988.

[3] Autos de Goiânia, Ciência Hoje, 7 (supplement) (1988) 48 pp.

[4] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), The Radiological Accident in Goiânia, IAEA, Vienna (1988) 149 pp.

[5] TRANJAN FILHO, A., O Acidente que Espantou o Mundo, to be published.

[6] ALVES, R.N., Private communication.

[7] PASCHOA, A.S., TRANJAN FILHO, A., ROSENTHAL, J.J., Revisiting Goiânia: Toward a final repository for radioactive waste, International Atomic Energy Agency Bulletin, 35 (1993) 28–31.

[8] LEENHOUTZ H.P., STOUTJESDIJK, J.F., The use of reference levels in the dose limitation procedures, The Science of the Total Environment, **45** (1984) 585–591.

[9] BECK, H.L., The physics of environmental gamma radiation fields, The Natural Radiation Environment II, (ADAMS, J.A.S., LOWDER, W.M., GESELL, T.F., Eds.), Conf. 7200805-P1 (1972) 101–133.

[10] LOWDER W.M., et al., Experimental investigation of the environmental radiation field, The Natural Radiation Environment II, (ADAMS, J.A.S., LOWDER, W.M., GESELL, T.F., Eds.), Conf. 7200805-P1 (1972) 101–133.

[11] CALDWELL, L.L., et al., Low level radioactive waste management, (WATSON, J.E., Jr., Ed.), EPA 520/3-79-002 (1979) 485–491.

DEVELOPMENT OF A STRATEGY FOR DECONTAMINATION OF AN URBAN AREA

XA0054880

J. ROED, K.G. ANDERSSON
Risø National Laboratory,
Roskilde, Denmark

Abstract

DEVELOPMENT OF A STRATEGY FOR DECONTAMINATION OF AN URBAN AREA.
The Chernobyl accident in 1986 lead to high level contamination in urban areas in different parts of Europe and showed the importance of preparedness in the optimisation of any mitigatory interference. To meet this demand, a method for development of a decontamination strategy for urban areas has been developed based on measurements of radionuclide distribution in the urban environment after the Chernobyl accident, calculations of dose and experimentally obtained data on effectiveness and cost of practicable clean-up procedures. The approach highlights where decontamination would be of greatest benefit in terms of dose reduction and cost.

1. INTRODUCTION

The Chernobyl accident showed that releases from nuclear power plants may give rise to high levels of contamination, also in rather remote city areas, subject to the weather conditions during the passage of the cloud carrying the radioactive material. The single most important radionuclide concerning the long-term external exposure of urban populations was found to be ^{137}Cs. The measurements made after the Chernobyl accident, however, also provided a data base, which could be used to deduce guidelines concerning countermeasures to reduce the collective doses received by urban populations due to such releases [1-5]. In the following, a stepwise approach for the development of such a contingency strategy is given.

2. DEVEOPMENT OF A STRATEGY

2.1. Identification of initial source term

The first step in the development of such a plan must be the identification of the relative initial levels of contamination on different surfaces in the urban environment. Here it is important to distinguish between the various possible modes of deposition. If deposition occurs in precipitation, the resulting distribution pattern will be very different from that caused by dry deposition. Again, there can be variations within a particular mode of deposition. For instance, a light shower giving very little surface run-off will lead to a different deposition pattern from that produced by prolonged heavy rain. Concerning dry deposition, Roed [6] found that the deposition velocities to urban surfaces were very small compared to those previously recorded for rural areas.

Estimates by Roed et al. [7] based on measurements of Chernobyl fallout in areas which received solely dry deposition and in areas in which deposition took place with heavy rain, lead to the typical relationships shown in Table I between radiocaesium concentration levels per unit area of different types of outdoor surface. These findings are consistent with measurements made in various parts of Europe [8-10]. If such information is used in the strategy development, it will only be necessary to actually measure the deposition to, for instance, a grassed area.

TABLE I. RELATIVE SOURCE STRENGTHS FOR VARIOUS SURFACES SHORTLY AFTER DEPOSITION OF CHERNOBYL FALLOUT CAESIUM, RELATIVE TO A CUT LAWN, WHERE THERE IS NO PENETRATION IN THE SOIL.

Surface type:	**Dry deposition**	**Wet deposition**
Gardens and park areas	1 00	0 80
Roofs of buildings	1 00	0 40
Walls of buildings	0 10	0 01
Streets, pavements and walkways	0 40	0 50
Trees in leaf	3 00	0 10

TABLE II. EXTERNAL LOCATION AVERAGED DOSES (MGY) FROM DIFFERENT CONTAMINATED OUTDOOR SURFACES ACCUMULATED OVER 1 AND 10 YEARS FOLLOWING A WET OR DRY DEPOSITION ON 26. APRIL OF 1 MBQ/M^2 ^{137}CS IN FOUR DIFFERENT ENVIRONMENTS DESCRIBED BY MECKBACH ET AL. (1988). CONTAMINATION ON INDOOR SURFACES IS NOT INCLUDED HERE.

Wet deposition 1 year	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det house	0 72	0 034	—	0 098	8 20
2-storey semidet house	0 39	0 010	—	0 026	3 13
2-storey terrace houses	0 15	0 008	0 320	0 022	1 89
5-storey block of flats	0 006	0 008	0 434	0 011	1 34
Wet deposition 10 years	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det house	2 58	0 250	—	0 133	55 6
2-storey semidet house	1 39	0 076	—	0 036	22 3
2-storey terrace-houses	0 54	0 061	0 822	0 031	13 1
5-storey block of flats	0 022	0 057	1 119	0 015	9 55
Dry deposition 1 year	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det house	1 79	0 34	—	2 93	9 01
2-storey semidet house	1 16	0 13	—	0 79	3 53
2-storey terrace-houses	0 37	0 08	0 26	0 68	2 04
5-storey block of flats	0 015	0 07	0 37	0 34	1 45
Dry deposition 10 years	**ROOFS**	**WALLS**	**ROADS**	**TREES**	**GRASS**
Single-storey det house	6 41	2 48	—	3 98	68 7
2-storey semidet house	3 44	0 76	—	1 08	27 4
2-storey terrace-houses	1 34	0 61	0 75	0 93	14 9
5-storey block of flats	0 054	0 57	1 11	0 46	10 9

In some cases, where deposition occurs in the absence of precipitation, the doses from indoor deposited contaminant aerosol may be significant. The indoor contamination level will especially be high, if the rate coefficient of ventilation (the fraction termed λ_r of air exchanged per unit time), the rate coefficient to deposition (the fraction termed λ_d of aerosols in the building deposited per unit time) and the filtering factor f (the fraction of aerosols in air entering the building which is not retained in cracks and fissures of the building structure) are all high.

2.2. Time-integrated dose calculation

Having defined the initial source strength, the next step in the strategy would be to calculate the relative dose-rate at different locations, indoor and outdoor, due to a deposition on the various urban surfaces (e.g. roofs, walls, paved areas, grass, trees, bushes). As these dose-rate contributions change with time it is imperative to gain sufficiently detailed knowledge on how the deposited radioactive matter will migrate with time in an urban complex.

From the large amount of data from field measurements conducted after the Chernobyl accident of contamination levels on urban surfaces a computer model, URGENT, has been developed [11-12]. This model calculates estimates of the dynamics of the radiocaesium migration processes which typically occur in a contaminated urban environment. The resulting gamma doses in a limited number of different urban complexes can be calculated from a library of dose conversion factors based on the calculations of Meckbach [13].

As an example of this part of the strategy, the accumulated doses over 1 and 10 years from a 1 MBq/m^2 ^{137}Cs contamination of external surfaces in different urban environments have been calculated with the URGENT model. The results are given in Table II. In the calculations, the relative deposition on the different surfaces was assumed to be as given in Table I. It was further assumed that the average person living in one of the four environments modelled spends 85% of the time at indoor locations, equally distributed between the different residential floors, 10% of the time in the garden and 5% on the streets and pavements. The Table indicates the relative importance o the various contaminated urban surfaces as contributors to dose. It must however be stressed that such calculations are only valid for assessment of the average dose in the area. More detailed calculations are required if the purpose is to investigate the dose to people living on a particular floor of the building.

So far we have not included the contributions to dose from indoor deposition. With the terms given in Section 1 of this paper, the relationship between the average deposited contaminant concentration on indoor surfaces (D_i) and the deposited contaminant concentration on a smooth, cut lawn (D_o) immediately following deposition can be calculated from:

$$D_i / D_o = (V_d / V_{dg})\, f\, \lambda_r / (\lambda_r + \lambda_d),$$

where V_d is the average local indoor deposition velocity and V_{dg} is the average deposition velocity on a grassed outdoor surface [12]. With the parameter values recorded by Roed and Cannell [14] in a series of measurements of Chernobyl ^{137}Cs deposition in furnished Danish houses, the figures given in Table III were calculated for the first year doses received from an indoor ^{137}Cs contamination corresponding to an outdoor level of 1 MBq/m^2 on a smooth cut lawn.

2.3. Evaluation of effectiveness and costs of feasible countermeasures

The third and final step in the strategy is to consider practicable methods for removing the contamination and to find out which procedures are best suited for the specific scenario in terms of cost and benefit.

Table IV shows estimates of achievable dose reduction factors and costs of dose reduction (including transportation and final disposal) [15-17]. In defining the appropriate specific surface. Table IV has been derived from a large number of decontamination experiments, both in situ and in the laboratory.

Combining Tables II and IV, values of cost and benefit of carrying out the procedures can be estimated. The result is presented in Table V. Here the total dose reduction achieved by cleaning each type of surfaces is given together with the individual cost.

The Table shows that following a dry deposition, street cleaning, removal of trees and shrubs and, especially, digging the garden are in practically all environments effective and inexpensive means of achieving very significant dose reductions and would therefore rank high in a list of priorities. Although the procedures for roofs and walls are shown not to be cost-effective on average, for instance roofs may in some cases be significant dose contributors to people living on the top floor of a building, and walls in certain city areas may also contribute significantly to dose.

TABLE III. ESTIMATED RECEIVED DOSES THE FIRST YEAR FOLLOWING CONTAMINATION (MGY), EQUIVALENT TO A TARGET POSITION 1M ABOVE GROUND IN A ROOM WITH HEIGHT 3 M AND IN THE CENTRE OF A 4M BY 4M GROUND AREA ASSUMING THE ABOVE MEAN INDOOR CONCENTRATIONS AND THAT 50 % OF THE TOTAL AMOUNT OF CAESIUM IS DEPOSITED ON THE FLOOR, WHILE THE REST IS EQUALLY DISTRIBUTED ON THE WALLS AND CEILING. RELATES TO A ^{137}CS CONTAMINATION ON A LAWN OF 1 MBQ/M^2.

f = 0.4	**$8_d = 0.36\ h^{-1}$**	**$8_d = 0.60\ h^{-1}$**	**$8_d = 1\ h^{-1}$**
$8_r = 0.3\ h^{-1}$	0.19	0.23	0.27
$8_r = 0.4\ h^{-1}$	0.22	0.27	0.33
$8_r = 0.6\ h^{-1}$	0.26	0.35	0.4
f = 0.6	**$8_d = 0.36\ h^{-1}$**	**$8_d = 0.60\ h^{-1}$**	**$8_d = 1\ h^{-1}$**
$8_r = 0.3\ h^{-1}$	0.29	0.35	0.41
$8_r = 0.4\ h^{-1}$	0.32	0.40	0.51
$8_r = 0.6\ h^{-1}$	0.39	0.53	0.65
f = 1.0	**$8_d = 0.36\ h^{-1}$**	**$8_d = 0.60\ h^{-1}$**	**$8_d = 1\ h^{-1}$**
$8_r = 0.3\ h^{-1}$	0.48	0.59	0.68
$8_r = 0.4\ h^{-1}$	0.54	0.68	0.84
$8_r = 0.6\ h^{-1}$	0.66	0.88	1.08

TABLE IV. ACHIEVABLE URBAN DOSE REDUCTION FACTORS AND COSTS OF DOSE REDUCTION IN AN URBAN AREA CONTAMINATED BY WET/DRY DEPOSITION. THE SUGGESTED METHODS ARE: FOR GARDEN AREAS : DIGGING. FOR STREETS: VACUUM SWEEPING. FOR TREES: CUTTING BACK OR REMOVAL. FOR ROOFS: HOSING OR SANDBLASTING. FOR WALLS: SANDBLASTING.

Surface type	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
DRF after dry deposition	1.9	1.9	2.0	50	10
DRF after wet deposition	1.5	1.2	1.7	10	8
Costs (ECUAm^{-2})	2	0.8	0.01	7	0.5

TABLE V. ESTIMATES OF COST AND BENEFIT OF DIFFERENT CLEAN-UP PROCEDURES FOR WET OR DRY CONTAMINATED URBAN ENVIRONMENTS. PERCENTAGE 1ST YEAR DOSE REDUCTION BY CLEANING THE SURFACES AND COSTS PER PERSON PER % DOSE REDUCTION (IN ECU).

Single-storey detached house	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep)	2 8	0 1	—	1 7	78 3
ECU/person per % dosered	22 50	218 00	—	237 36	1 01
% dose reduction (dry dep)	5 2	4 1	—	23 7	42 3
ECU/person per % dosered	16 21	7 43	—	11 97	1 87
Two-storey semidet. house	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep)	3 8	0 1	—	1 2	76 2
ECU/person per % dosered	16 57	458 08	—	160 87	0 59
% dose reduction (dry dep)	8 8	1 0	—	24 1	45 4
ECU/person per % dosered	10 71	45 31	—	7 12	1 05
2-storey terrace house row	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep)	2 2	0 1	5 6	1 5	68 1
ECU/person per % dosered	29 05	260 44	0 06	79 73	0 73
% dose reduction (dry dep)	6 0	1 1	4 2	23 9	42 7
ECU/person per % dosered	29 05	31 88	0 02	3 71	1 09
5 storey block of flats	**Roofs**	**Walls**	**Streets**	**Trees**	**Gardens**
% dose reduction (wet dep)	0 2	0 1	10 2	1 0	64 2
ECU/person per % dosered	179 47	145 27	0 02	6 28	0 16
% dose reduction (dry dep)	0 4	1 6	7 8	22 3	43 1
ECU/person per % dosered	55 92	47 33	0 01	0 22	0 24

In the case of wet deposition, the garden areas would be given first priority since a considerable dose reduction (78%) may be achieved at a relatively low cost. Street cleaning would also be useful and very inexpensive.

If the actual conditions for indoor deposition, in terms of the previously mentioned parameters, are known the corresponding dose contribution can be deduced from Table III, and this can form the basis for an evaluation of the relative importance of indoor decontamination. A comparison of Tables II and III shows that the dose contribution from indoor surfaces can be significant in a dry deposition scenario.

3. CONCLUSION

A contingency plan for clean-up of contaminated urban areas has been outlined. From measurements following the Chernobyl accident, the typical distribution with time of radioactive matter in an urban complex has been identified. The resulting time-integrated doses have been found by computer modelling employing the large amount of data obtained from in situ Chernobyl fallout measurements. On this background, the effectiveness of practicable countermeasures in terms of dose reduction and costs has been evaluated.

The analyses of wet contaminated urban scenarios showed that decontamination of gardens should be given first priority, since a reduction of the total external dose by as much as 78% can be achieved by a special garden digging procedure (skim-and-burial digging). Street cleaning should be given second priority, as it can be performed very inexpensively. In dry deposition scenarios, also removal of the trees seems cost-effective. On average, the effect of decontamination of walls and roofs was found to be small, and clean-up of such surfaces would be given a low priority.

Such calculations, together with for instance the recommendations of the ICRP could form a set of guidelines on which procedures to follow subsequent to an accidental release.

REFERENCES

[1] ROED, J., JACOB, P., Deposition on Urban Surfaces and Subsequent Weathering, Proceedings from the seminar on methods and codes for assessing the off-site consequences of nuclear accidents, Athens (1990).

[2] ROED, J., Modelling of Run-off and Weathering Processes, presented at the MARIA Workshop at Kernforschungszentrum Karlsruhe (1988).

[3] ROED, J,: Run-off and Weathering of Roof Material Following the Chernobyl Accident, Rad. Prot. Dos., Vol.21, No.1/3 (1987) 63.

[4] ROED, J., The Distribution on Trees of Dry Deposited Material from the Chernobyl Material from the Chernobyl Accident, presented at the joint CEC/OECD (NEA) Workshop Recent Advances in Reactor Accident Consequence Assessment, Rome, Italy (1988).

[5] ROED, J., SANDALLS, J., The Contamination Levels of Chernobyl Fallout on Different Surfaces in Gävle in Sweden, Proceedings of the VXth Regional Congress of IRPA on the Radioecology of Natural and Artificial Radionuclides, FS–89–48T (1989) 1013–4506.

[6] ROED, J., Dry Deposition of Urban Surfaces, Risø report R–515 (1985).

[7] ROED, J., ANDERSSON, K.G., SANDALLS, J., Reclamation of Nuclear Contaminated Urban Areas, presented at the BIOMOVS Symposium and Workshop on the validity of environmental transfer models, Stockholm, 8–12 October 1990.

[8] KARLBERG, O., SUNDBLAD, B., A study of Weathering Effects on Deposited Activity in the Studsvik and Gävle Area, Studsvik Technical Note NP–86/78 (1986).

[9] SANDALLS, F.J., GAUDERN, S.L., Radiocaesium on Urban Surfaces in West Cumbria Five Months After Chernobyl, draft report, Environm. & Medical Sci. Div., Harwell Laboratory (1986).

[10] JACOB, P., MECKBACH, R., MÜLLER, H.M., Reduction of External Exposure from Deposited Chernobyl Activity by Run-off, Weathering, Street Cleaning and Migration in the Soil, Rad. Prot. Dos., Vol.21, No.1/3 (1987) 51–57.

[11] ANDERSSON, K.G., Users Guide to URGENT: A Multi-compartment Computer Model System which Evaluates the Impact of Radiocaesium Movement in the Urban Environment, Contamination Physics Group, Environm. Sci. & Technology, Risø Natl. Lab. (1994).

[12] ANDERSSON, K.G., URGENT — A Model for Prediction of Exposure from Radiocaesium Deposited in Urban Areas, presented at the GSF/CEC/IAEA/GAST Workshop on Dose Reconstruction in Bad Honnef, 6–9 June 1994.

[13] MECKBACH, R., JACOB, P., PARETZKE, H.G., Gamma Exposures due to Radionuclides Deposited in Urban Environments, Part 1: Kerma Rates from Contaminated Urban Surfaces, Rad. Prot. Dos., Vol.25, No.3 (1988) 167–179.

[14] ROED, J., CANNELL, R.J., Relationship Between Indoor and Outdoor Aerosol Concentration Following the Chernobyl Accident, Rad. Prot. Dos., Vol.21, No.1/3, (1987) 107–110.

[15] ANDERSSON, K.G., ROED, J., Cost-benefit Analysis on Clean-up of Radioactive Contaminated Urban Areas, in Lehto, J. Clean-up of Large Radioactive Contaminated Areas and Disposal of Generated Waste, Final Report of the KAN2 Project, Tema Nord 1994:567, ISBN 92 9120 488 9, ISSN 0908–6692. (1994).

[16] ROED, J., ANDERSSON, K.G., Using In Situ Gamma-ray Spectrometry to Guide Clean-up of Radioactive Contaminated Urban Areas, presented at the XV Mendeleev Congress on General and Applied Chemistry, Minsk, 24–29 May 1993.

[17] SALONEN, P., LEHTO, J., Costs of Transportation and Final Disposal of Clean-up Waste, Internal rep., Dept. of Radiochemistry, University of Helsinki, Finland. (1993).

XA0054881

INDIVIDUAL MONITORING AND DOSIMETRY: THE GOIÂNIA EXPERIENCE

J.L. LIPSZTEIN, D.R. MELO, C.A.N. OLIVEIRA, L. BERTELLI
Instituto de Radioproteção e Dosimetria,
Rio de Janeiro, Brazil

Abstract

INDIVIDUAL MONITORING AND DOSIMETRY: THE GOIÂNIA EXPERIENCE.

Several people were contaminated with ^{137}Cs in an accident involving the stealing and breaching of a radiotherapy source in Goiânia, Brazil. A drug known as Prussian Blue was administered to some contaminated individuals to enhance Cs elimination from the body.

Individuals internally contaminated were monitored for the two first months, exclusively by in vitro bioassay, i.e., urine and faeces analysis. After that period of time a field whole-body counter was set up in Goiânia and individuals started to be monitored in vivo, on a regular basis.

The total internal committed doses and the effect of Prussian blue treatment have been evaluated. For adults, the biological half-time (T_2) under PB treatment was reduced to an average value around to 31% of the half-time after finished treatment. For adolescents (T_2) was reduced to an average value around to 54% and for children was reduced to an average value around to 57%.

A weight dependent biokinetic study of ^{137}Cs retention in humans was conducted. Data from 10 girls and 7 boys, aged 1 to 10 y old, as well as from 10 adolescents: 4 females and 6 males, and from 30 adults: 15 females and 15 males, contaminated in the accident, were used in this study. A planned experiment with beagle dogs were carried out to furnish some further data for our study. Based on these data, a three terms exponential equation is suggested to describe the ^{137}Cs retention in the body, the first-term associated with a very short half-time, the second with a longer half-time and the third term with a very long half-time, of the order of 400 to 570 days and relating to a retention fraction of only 0.1%. A table of weight, age and sex specific half-times for the second term is suggested.

1. INTRODUCTION

In September 1987 a ^{137}Cs medical teletherapy source was stolen and removed from its shield. The rupture of the CsCl source containing 50.9 TBq of ^{137}Cs exposed persons, externally and internally. Sixteen days elapsed between the rupture of the source and the discovery by authorities. Internal contamination was mainly due to ingestion, resulting from eating with contaminated hands or from contaminated utensils.

Prussian Blue[1] was used to enhance the elimination of ^{137}Cs from the body, in dosages that varied from 3 to10gd^{-1} for adults and adolescents and from 1 to 3gd^{-1} for children.

This paper summarises our main conclusions on ^{137}Cs internal contamination. Data from Goiânia victims were complemented by data from an experiment with beagle dogs, injected with ^{137}Cs (Melo et al, 1994).

2. MONITORING FOR INTERNAL CONTAMINATION IN EMERGENCY SITUATIONS

Individuals were monitored for the first two months, exclusively by excreta bioassay. In November an improvised whole body counter was set up in the General Hospital of Goiânia. A 20 cm x 10 cm NaI(Tl) detector collimated by 5 cm of lead wrapped around the crystal was positioned at 2 m from the floor. Seven layers of 2 mm lead sheets, 2.0 m x 1.0 m,

[11] 68% Fe[Fe(CN)], Radiogardase-Cs, Hey Chemisch- pharmazentiche Fabric, Berlin.

were overlaid on the floor below the detector. This system proved adequate for high activity measurements. It had the same efficiency for adults and children and it presented a minimum detection limit of 9 kBq for 2 min. counting. This whole body counter was in operation until January 1988, when it was transferred to a house bought by CNEN at 57th Street, where the ^{137}Cs source was ruptured. As the background counting rate was high due to ^{137}Cs roof contamination, the top part of the detector received additional shielding. The minimum detection activity for this arrangement was 7.3 kBq for 2 min. counting (Oliveira et al, 1991).

The excreta samples from contaminated individuals were shipped by air to Rio de Janeiro to be processed at our in-vitro laboratory. Complete 24 h urinary and faeces collections were requested but this instruction was rarely followed.

As data from excreta samples were analysed we concluded that "in vitro" analysis is very useful for screening individuals with internal contamination and for qualitative information on Prussian Blue action. Patients that were not treated with the medicament excreted Cs mainly via urine, while the faeces/urine Cs concentrations ratio increased for the people that took the drug. We concluded that for quantitative information it is necessary to obtain a large number of samples since there was a high fluctuation of data. During a certain period of time both "in vitro" and "in vivo" bioassay were used. The half-lives from in vivo monitoring data were similar to the half-lives from in vitro analysis, when we compared the same time period. "In vivo" monitoring techniques were much simpler to use and should be the monitoring method of choice, if available.

3. PRUSSIAN BLUE

Prussian Blue (PB) significantly increased the concentration of ^{137}Cs in faecal excretion which became the prevalent pathway of caesium elimination from the body. For adult individuals, the average ^{137}Cs biological half-time was the same for all three PB dosages,
25 $\pm$ 9 d, 25 $\pm$ 15 d and 26 $\pm$ 9 d respectively, when 3, 6 and 10 g were administered. The biological half-times of ^{137}Cs, under PB treatment decreased to average values of 25 $\pm$ 11 d for adults, 30 $\pm$ 10 d, irrespective of the dosage of PB that was administered (3, 6 and 10 g) and of the age of the individual. The half-times under PB treatment were compared to the half-times after treatment was discontinued for human data and the half-time for treated and untreated dogs were also compared. The average ratios of biological half-times were very similar for humans and dogs, as shown in Table I. For adults 90% of the internal doses, under PB treatment were committed in the first 2-3 months after ^{137}Cs intake. This information might be useful, when establishing the duration of treatment with the drug (Melo et al, 1994).

TABLE I. REDUCTION OF BIOLOGICAL HALF-TIME (T_2) DUE TO ACTION OF PRUSSIAN BLUE FOR HUMANS AND DOGS (T_2 UNDER PB TREATMENT / T_2 AFTER FINISHED TREATMENT).

Humans	**T_2 PB/ T_2 no PB**	**Dogs**	**T_2 PB/ T_2 no PB**
Children	0.57	4.7 mo and 2.4 y old	0.55
Adolescents	0.54		
Adults	0.31	13 y old	0.37

4. CAESIUM BIOKINETIC MODEL

According to publication 56 of the ICRP (ICRP 1989) the whole body ^{137}Cs retention may be described by a uniform distribution in the body, with a fraction of caesium being excreted in a short time and a fraction retained in the body for a longer period. A biokinetic model for caesium was derived based on three set of data: people internally contaminated in the Goiânia accident; an experiment with beagle dogs of five different ages; the literature. The caesium retention model consisting of a sum of three exponential terms. The first term represents the elimination of urine of ^{137}Cs filtered by the kidneys within a few hours of its entry into blood. The parameters of the first term were derived from an experiment with beagle dogs and data from literature. The retention fraction (a_1) is a function of body weight (negative correlation). There was no significant correlation between the first-term half-time (T_1) and any biological parameter tested.

The second retention term reflects the progressive loss in urine and faeces of caesium retained in issues. Based on data from 17 children (10 girls and 7 boys 1–10 y old), 10 adolescents (4 females and 6 males) and 30 adults (15 females and 15 males) contaminated in the accident, was found that the biological half-time related to the second term (T_2) is a function of body weight until adulthood is reached. For the adults there was a significant difference in half-times between the male and female and no correlation with age or weight (Melo et al, 1994). The second term was also based on data from an experiment with beagle dogs.

Five different age groups (3 months, 4 months, 2,5 y and 13 y) were used in this experiment. Each group consisted of 2 male dogs. A single injection of approximately 44 Bq of ^{137}Cs was given to each dog and whole body measurements in intervals of two days were performed. Twenty four hours of excreta was collected daily and measured. The dogs were sacrificed 41 days after the ^{137}Cs injection and their tissues and organs were dissected and measured. The retention of ^{137}Cs in the dogs' organism was well described by a two term exponential equation, representing a short term retention and a longer term retention. There was a strong statistical correlation of the long term half-life with body weight for the dogs, up to 2.5 years. At the time of sacrifice, most of the Cs in the body was located in the skeletal muscle tissue, which represents 40% of the total body (Melo et al, 1994).

5. PROPOSED MODEL FOR ^{137}CS

Most physiological cycles show a significant correlation to a fractional power of body weight (Stahl, 1962, Lindstedt, 1981, Eberhardt, 1967). This relationship was tested for the half-life of Cs in the organism and we have obtained the following equations:

– Dog's data: $t^{1/2} = 4.6\ W^{0.71}$ ($r^2 = 0.92$, $p < 0.05$)

– Goiânia's data: $t^{1/2} = 4.9\ W^{0.64}$ ($r^2 = 0.99$, $p < 0.05$) (youngsters up to 16 y)

where $t^{1/2}$ is the half-time related to 2nd term, W is the body weight in Kg.

TABLE II. PROPOSAL FOR T2WEIGHT SPECIFIC DISTRIBUTION FOR YOUNGSTERS ($T^{1/2} = 4.9\ W^{0.64}$)

Range body weight (kg)	$T^{1/2}$ (days)
3 — 6	13
11 — 15	25
16 — 30	37
31 — 40	49
41 — 50	57
51 — 60	65
61 — 70	72

Four years after the accident, a small number of individuals still had measurable ^{137}Cs activities in their bodies. Data from these individuals indicate a third-term in the retention equation, with a longer half-time (T_3) of the order of 400 to 570 days, and corresponding to a retention fraction of less than 0.001 (a_3), Melo et al., 1994. The third exponential term may reflect retention in a subcellular fraction of the skeletal muscle.

As conclusion, we suggest the values for the first-term retention fraction (a_1) equal to 0.25 to youngsters up to 16 y old and 0.15 to adults (male and female). The biological first-term half-time (T_1) equal to 3 d for all age and weight groups. The second-term biological half-time values (T_2) for the youngsters are shown in Table II. For the adults, we suggest an average half-time (T_2) of 65 d for females (range 39 to 90 d) and 90 d for males (range 66 to 141 d). We further suggest a third component with a half-time (T_3), in the range of 400 to 570 d, corresponding to 0.1% of the intake.

REFERENCES

[1] EBERHARDT, L.L., Relationship of Caesium 137 half-life in humans to body weight, Health Physics **13** 1 (1967).

[2] ICRP, Age Dependent Doses to Members of the Public from Intake of Radionuclides: Part 1, ICRP publication 56, Pergamon Press, Oxford (1989).

[3] LINDSTEDT, S.L., CALDER, W.A., Body size, physiological time, and longevity of homeothermic animals, The quarterly Review of Biology **56** 1 (1981).

[4] MELO, D.R., LIPSZTEIN, J.L., OLIVEIRA, C.A.N., LUNDGREN, D.L., MUGGENBURG, B., GUILMETTE, R., A ^{137}Cs age dependent biokinetic study, sent for publication, Health Physics (1994).

[5] OLIVEIRA, C.A.N., LOURENϴ, M.C., DANTAS, B.M., LUCENA, E.A., Design and Operation of a Whole-Body Monitoring System for the ÇĐÙUãÙÒ Radiation Accident, Health Physics, **60** 1 (1990).

[6] STAHL, W.R., Similarity and dimensional methods in biology, Science 137 (3523) (1986).

XA0054882

^{137}Cs METABOLISM IN PREGNANT WOMEN

D.R. MELO, J.L. LIPSZTEIN, C.A.N. OLIVEIRA, L. BERTELLI
Instituto de Radioproteção e Dosimetria/CNEN,
Barra da Tijuca, Rio de Janeiro,
Brazil

Abstract

^{137}Cs METABOLISM IN PREGNANT WOMEN.

Data from two pregnant women contaminated with ^{137}Cs, body burdens of 0.2 and 300 MBq, respectively at the time of the Goiânia accident, were compared. The first one, with lower body burden was exposed during the fourth month of pregnancy, while the second became pregnant three years and eight months after ^{137}Cs intake. For the first woman ^{137}Cs concentrations were equal for the mother, infant and placenta, indicating an easy and homogeneous transport of ^{137}Cs from mother to foetus. The whole body monitoring data from the second woman, who became pregnant four years after intake, did not show a reduction in biological half-life during the pregnancy. Cs concentration in the mother was found to be 13 times higher than in the infant. One possible reason for this result is that four years after intake, Cs is supposed to be concentrated mainly in skeletal muscle tissue. During the pregnancy the blood flux becomes higher in most of the organs and tissues except brain, liver and skeletal muscle tissue.

1. INTRODUCTION

According to the ICRP publication 56, the ^{137}Cs retention in the adult's body can be adequately expressed by the sum of two exponential components of the form:

$$R(t) = 0.1\ e^{-0.693t/2} + 0.9\ e^{-0.693t/110} \qquad \text{(eq.1)}$$

Retention half-lives for the long-term component in females are reported to be less than in males. It has been reported at ICRP publication 56 average values of 61 and 65 days, for females. Melo *et al.* (1994) reported an average value of 65 days from women internally contaminated in the Goiânia accident.

Bengtsson *et al.* have published that pregnancy accelerates the ^{137}Cs excretion from the female body, and the half-lives becomes 50 to 65% of the non-pregnant women. Possible mechanisms for the decreased retention of Cs in pregnancy might be: elevated oestrogen, progesterone and aldosterone levels, rapidly growing tissue mass, increased metabolic rate or changes in renal function. Zundel *et al.* have investigated some of these possibilities through the oral administration of two hormones (oestrogen and progesterone) to normal women, but it appeared to have little or no effect on caesium metabolism, but it is unknown whether the half-lives might have been altered if the injection, or if other hormones had been used. Another possible reason for the enhancing of caesium elimination from the body might be due to a 50% increase in the blood flux that occurs during pregnancy (Rezende, 1982).

This paper is a comparison between data from two women that became contaminated with ^{137}Cs in the Goiânia accident. The first one became internally contaminated in the fourth month of pregnancy and the second one became pregnant three years and eight months after ^{137}Cs intake. A complete analysis of the data from the first pregnant woman has been published by Bertelli *et al.*, 1992.

2. 1st CASE — WOMAN WHO BECAME INTERNALLY CONTAMINATED WITH ^{137}Cs IN THE FOURTH MONTH OF PREGNANCY

The ^{137}Cs body burdens of the mother and infant, when the baby was born, are summarised in Table I. The values of ^{137}Cs concentration for mother, placenta and infant are similar. This similarity indicates an easy and homogenous transport of caesium from mother to foetus and also a lack of any placental barrier for ^{137}Cs.

TABLE I. DATA FROM PREGNANT WOMAN THAT BECAME INTERNALLY CONTAMINATED IN THE FOURTH MONTH OF PREGNANCY, AT TIME OF BIRTH

#	Activity (Bq)	Concentration (Bq/kg)
Mother	61,087	912
Infant	3,885	971
Placenta	377	919

Figure 1 shows the ^{137}Cs retention curves of the mother and infant. Just one measurement was performed during pregnancy, in the sixth month. The second measurement was done one week after birth. A ^{137}Cs biological half-life of 46 days was estimated for the mother, through regression analysis using a single exponential model for the set of data after birth. This biological half-life refers to the long-term of Cs retention equation, since the first whole body measurement was done two months after intake. It is interesting to note that the single datum from measurement performed during pregnancy fits well in the regression curve of the data taken after delivery, contradicting literature. As is seen in Figure 1, during the first 60 days, the ^{137}Cs body burden of the infant did not change. In this period of time breast feeding was the only source of nourishment. These data reflect an equilibrium between intake

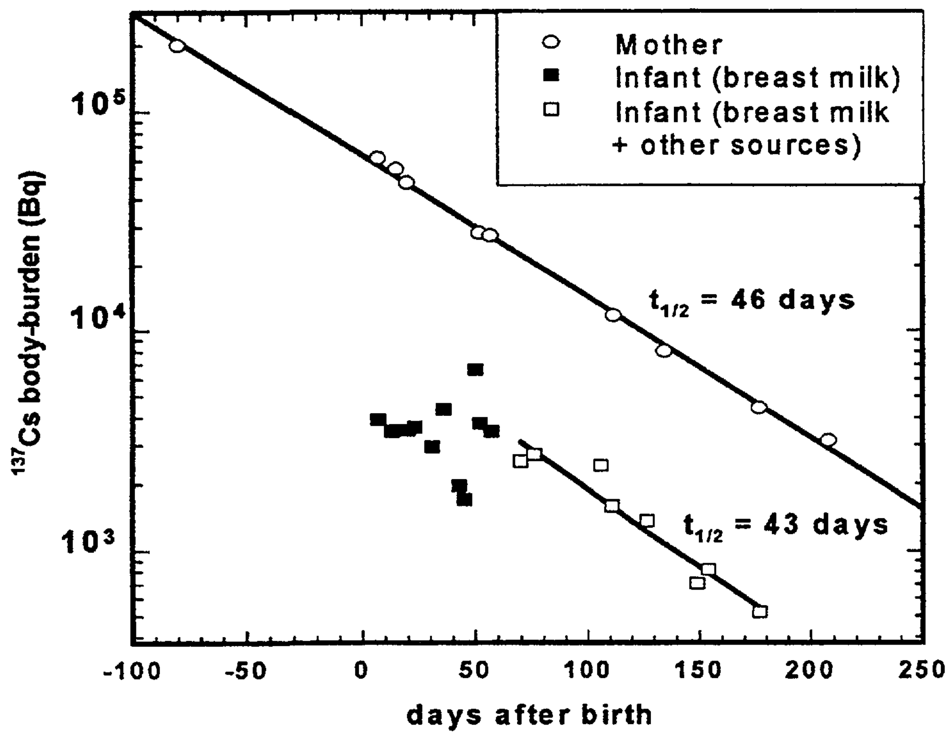


FIG. 1. ^{137}Cs retention curves of woman that became contaminated in the fourth month of pregnancy and her baby.

from mother's milk and loss by excretion. After this period, the baby mixed breast milk and other sources of nutriment. The biological half-life estimated for this period, until 7 months of age, was 43 days, similar to the mother.

3. 2nd CASE — WOMAN WHO BECAME PREGNANT THREE YEARS AND EIGHT MONTHS AFTER ^{137}Cs INTAKE

This woman was highly contaminated during the Goiânia accident. Some data from mother, infant and placenta are presented in Table II. There was no measurable caesium activity in the placenta. The caesium concentration in the mother's body was 13 times higher than in the infant's body. One possible reason for this result is that almost four years after intake, caesium is supposed to be concentrated mainly in skeletal muscle tissue. According to Rezende, 1982, during the pregnancy the blood flux becomes about 50% higher in most of organs and tissues except brain, liver and skeletal muscle tissue.

TABLE II. DATA FROM WOMAN THAT BECAME PREGNANT THREE YEARS AND EIGHT MONTHS AFTER INTAKE

#	Activity (kBq)	Concentration (Bq/kg)
Mother (initial body burden)	300,000	
Mother (at time of birth)	9,77	132
Infant	0.037	10
Placenta	< MDTA[a]	

[a] MDTA = 0.16 Bq (for 6 hours of counting time)

Figure 2 shows the ^{137}Cs retention in this woman for the whole period that she was monitored in the whole body counter. The first portion of the curve represents the 7 months during which period she was submitted to Prussian blue treatment, in dosages that varied from 6 to 10 grams per day. The biological half-life was 37 days. The second portion, for which the biological half-life was 58 days, represents the period after Prussian blue treatment. This value of biological half-life is within the range of half-lives from the Goiânia's women that never

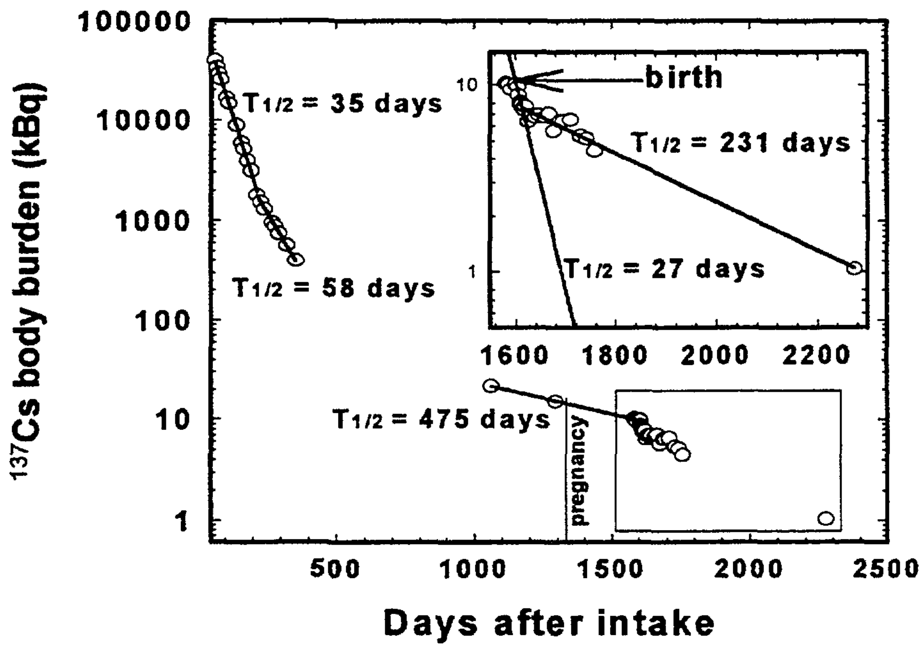


FIG. 2. ^{137}Cs retention curve of woman who became pregnant three years and eight months after intake

were submitted to Prussian blue treatment (average: 65 days, range 43 to 90 days). The third biological half-life might refer to a third component in retention equation (eq.1) with a long half-life, 475 days. It might be related to uptake in skeletal muscle tissue, since the largest

fraction of ^{137}Cs in the body is located in this tissue, Melo 1994. Unfortunately we have only data from the last month of pregnancy and they seem to fit in the same regression curve of the data before pregnancy. In this case, pregnancy again, did not modify ^{137}Cs retention, as described in literature. During the first sixteen days after birth, the ^{137}Cs biological half-life decreased to 27 days. This decrease might be associated to the loss of water from the body. During this period of time a strong correlation between ^{137}Cs body burden and body weight

($r^2 = 0.99$), was found. This woman had a high water retention during pregnancy and probably when she eliminated this extra water from her body the ^{137}Cs was removed together with the water. After this period, the biological half-life increased to 231 days.

REFERENCES

[1] BENGTSSON, L.G., NAVERSTEN, Y., SVENSSON, K.G., Assessment of Radioactivity in Man, II, 21, IAEA, Vienna (1964).

[2] BERTELLI, L., OLIVEIRA, C.A.N., LIPSZTEIN, J.L., WREN, M.E., A case study of the transfer of ^{137}Cs to the human foetus and nursing infant, Radiation Protection Dosimetry **41** 2/4 (1992) 131–136.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Medical handling of accidentally exposed individuals, Safety Series 88, IAEA, Vienna (1988).

[4] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Limits for intakes of radionuclides by workers, Oxford, Pergamon Press, ICRP Publication 30; Ann. ICRP **2** 3/4 (1979).

[5] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent doses to members of the public from intake of radionuclides, Oxford, Pergamon Press, ICRP Publication **56** (1989).

[6] MELO, D.R., LIPSZTEIN, J.L., OLIVEIRA, C.A.N., LUNDGREN, D.L., MUGGENBURG, B., GUILMETTE, R., A ^{137}Cs age-dependent biokinetic study, sent for publication in Health Physics (1994).

[7] REZENDE, Jorge, Obstetrícia, Editora Guanabara Koogan S.A., Rio de Janeiro, RJ (1982).

[8] ZUNDEL, W.S., TYLER, F.H., MAYS, C.W., LLOYD, R.D., WAGNER, W.W., PENDLETON, R.C., Short half-times of caesium-137 in pregnant women, Nature 221(5175) (1969) 89–90.

CALIBRATION OF WHOLE-BODY COUNTERS FOR ACCIDENT IN VIVO MONITORING

G.R. LAURER
Nelson Institute of Environmental Medicine,
New York University Medical Center,
Tuxedo, New York,
United States of America

Abstract

CALIBRATION OF WHOLE-BODY COUNTERS FOR ACCIDENT IN VIVO MONITORING.

This paper points out the importance of implementing transportable *in vivo* measurements laboratories in countries like Brazil where there is a large number of people directly and indirectly exposed to radionuclides. These units should be used mainly in emergency situations involving internal and external contamination of workers and public. Nevertheless such laboratories may also be used for simultaneously collecting and processing a great variety of biological and environmental samples not only for emergency purposes but also as part of a more comprehensive radiological survey of working and environmental conditions. The development of new techniques for calibrating the detection systems, i.e., physical and mathematical anthropomorphic phantoms, increases the range of applications for such laboratories and allows the obtention of quick results when and where it is necessary.

1. INTRODUCTION

In addition to discussing the calibration of whole-body counters for accident monitoring, I also want to briefly discuss emergency preparedness — not in the broadest sense — but on the topic of a field laboratory to determine levels of radioactivity in people, and in samples — both from people and from the environment.

At the time of the Goiânia accident, I was not able to help directly, except via a few impassioned phone calls from my friend and colleague Carlos Nogueira Oliveira, who had been given the responsibility of constructing a whole body counting facility in Goiânia. Later, in the months following the accident I was able to participate more closely, helping Mr. Nogueira in some further in-vivo counting tasks there. The problems he encountered in setting up a state-of-the-art gamma-ray counting facility in the field — "from scratch" so to speak — and the experience he gained solving those problems, are described in detail in his Ph.D. thesis. He had to accomplish this task quickly, amidst the extreme agitation and confusion of the early and most difficult days and weeks after the accident, refining the system as needed. It was a very difficult task, done within severe time restraints and in very arduous circumstances.

My experience of those first days and weeks after the accident and the problems of constructing, calibrating and maintaining a counting facility in the field is derived from those early phone calls from Mr. Nogueira and mainly from reading his thesis. Though this is second-hand experience at best, it has led me to conclude that the key to rapid response to an emergency call for a counting facility to determine internal levels of radioactive contamination is to have the facility equipped and ready to be deployed before the accident. After all, when there is a life-threatening fire, firemen don't wait until they get to the scene of the fire to design and build a water-pumping system before they can start to put it out. All fire companies have emergency response laboratories that are mobile, ready to move and equipped with the tools they need to respond to any emergency, before it happens. Why should a radiation emergency be any different. This is not to say that radiation emergency vehicles do not exist anywhere — they do. I refer rather to a mobile counting laboratory.

2. TRANSPORTABLE COUNTING LABORATORY

For the task of field radioactivity counting — especially in-vivo measurements — the most important item in any emergency-response armamentarium should be a vehicular-based, counting laboratory. The words "vehicular-based" will mean different things to different people. Thus the size and design of such a vehicle is better left to automotive engineering experts — guided with the input of those who have experienced emergency conditions in the field and understand its special needs. The details of which equipment to incorporate is also open to debate, however some of it is generic to the task. Minimally, this would include:

2.1. A Whole-Body Counting System

By utilising a design similar to the final system of Mr. Nogueira, with a shielded detector over a comfortable reclining chair, a geometry is established at a fixed height, simplifying the shielding design as well as calibration of the detectors. The reclining chair is important for the psychological well-being and co-operation of potential subjects. The system would also include one of the currently available computer-based, multi-channel analysers for measurement and analysis of gamma-ray spectra.

2.2. Hyper-Pure Germanium Detectors

To handle the potentially very wide ranges of count-rates, again borrowing from the experience of Mr. Nogueira, the in-vivo system should utilise several smaller detectors — shielded such that one detector at a time can be used — or two, or three, or four — depending on the contamination levels. NaI detectors were used at Goiânia because they were available. These detectors have limited spectral resolving ability however and, in an accident involving the need for quantifying the amounts of several different nuclides, each emitting several gamma-rays which may overlap in a NaI spectrum, they would hamper effective accident response. Thus, the potential need for good spectral resolution is met by specifying at least two or more hyperpure germanium detectors — to be shared between the in-vivo system and the small sample counting system. They are recommended even though the need for liquid nitrogen to cool them will add to logistical problems. Fortunately hyperpure germanium detectors require cooling only during operation. If liquid nitrogen is in short supply, one has only to remove the bias voltage to store them without damage until the liquid nitrogen is replenished. This latter requirement of course leads to the logical conclusion that two or more NaI detectors should also be included in the mobile laboratory. It would be a serious faux pas to arrive at the scene of an accident, quickly set up and get everything operating only to find that someone forgot the liquid nitrogen.

2.3. X-ray Fluorescence Analysis

HPGe detectors provide an additional advantage and, though this meeting is perhaps not the right forum, allow me to inject at this point a plea for attention to another serious and perhaps more insidious problem in terms of human health, and that is heavy metal contamination — Pb, Hg, As, Ni, Cd, etc. The United States is experiencing it now and, as the world community becomes more industrialised, other countries will begin to experience it. Although it is not an emergency in the same sense that radiation accidents such as Goiânia or

Chernobyl are, it is a very serious problem nonetheless. This is only to point out that the recommended germanium detectors are also the choice for detection of high Z elemental X rays and are being used world-wide for analysis of metals, both in-situ and, for some metals, in-vivo. The technique used is energy-dispersive x-ray fluorescence analysis (EDXRF), which provides simultaneous analysis of all the elements in a given sample by detection and measurement of the x-rays emitted during sample excitation. The x-ray analyses would employ the same multi-channel analyser used for the gamma-ray measurements. Thus to provide EDXRF capability for analysis of heavy metals, the mobile laboratory would require the addition of only the x-ray analysis software and a means of producing the excitation of the elements in the sample. The latter is easily provided in the form of a radioactive isotope, although small x-ray tubes are also used.

2.4. Effective Shielding

As Mr. Nogueira showed, shielding the detector around the top and sides was important to reduce background due to ^{137}Cs contamination on the roof of the building he used to house his final system. A vehicular-based installation would also need to include enough shielding under and around the reclining chair to reduce background from any ground contamination. Lead bricks are easy to obtain and would provide a stable shielding platform which is simple to assemble.

2.5. Sample Counting Facility

A separate facility is needed for determining levels of radioactivity in small samples, including not only faeces and urine from the subjects, but also air, water and soil samples to help determine the extent and levels of contamination in the environment. To avoid cross-contamination, this is best done in another room with its own shielded detectors, within the vehicle, but separated from the in-vivo counting area.

2.6. Sample Preparation Area

Space for a small chemistry lab, with provision for secure storage of the needed glassware, chemicals, acids, etc., in addition to perhaps a small muffle furnace for ashing, hot plates, a small refrigerator for sample storage, etc. A supply of liquid nitrogen in small tanks could also be stored here.

2.7. Power Generator

In anticipation that centralised power may be out or not available, provision should be made for the generation of stabilised and filtered power to the vehicular-based laboratory.

I am certainly not the first to have thought of a transportable counting system. Commercial mobile in-vivo counters are used in the United States. In fact, Mr. Nogueira and I discussed such a system long ago, when he was installing the whole-body counter shield at IRD. There is no doubt that a mobile laboratory for use in accident situations, which includes an in-vivo counting facility would be an expensive undertaking — and a difficult design problem to try to take into account all of the possible conditions in which it might be used and all the places if might be required to go. Nonetheless in terms of emergency preparedness, it is a logical and necessary piece of equipment that should be in place in any country which is involved in the use of radioactivity. As we have all seen, no matter how carefully plans to the contrary are made, accidents — often serious and fatal — do happen. We should therefore make use of all of the technology and expertise available to enhance the ability of emergency teams to respond quickly and be immediately effective in alleviating the consequences of accidents. Although each country in need of such a vehicle could design their own and indeed, some already have them in one form or another — although none I know of with all the capabilities discussed — it would probably be best, as said earlier, to leave the design effort to the engineering experts who in turn would rely on the input of the entire radiation protection community — perhaps through a forum such as this — to provide a mobile counting laboratory with the broadest, most useful capabilities.

3. CALIBRATION OF IN-VIVO MEASUREMENTS

In any accident involving intake of high levels of radioactivity by humans, it is important to know, as accurately as possible, the levels of radioactivity ingested, because — depending on the isotope, its chemical form, distribution, etc. — subsequent medical treatment will, in part, depend on the levels measured. Thus careful calibration of the counting efficiency of the in-vivo measurement is of paramount importance. Calibration of in-vivo measurements is not a trivial task, due to the complex variability of body size, shape and thickness, density differences between bone, muscle and fatty tissue, non-homogeneous distribution of the activity within the body, etc. etc. All of these parameters, along with variable absorption and scattering coefficients within the different tissues, make the calibration dependant on gamma energy and sensitive to detector/subject geometry — i.e. the distance from the detector to the various parts of the body; trunk, head, legs, etc., and — for non-uniformly distributed radioactivity — the distance from the detector to the variable sizes, thickness and positions within the body of the organs in which the activity may be incorporated.

Various methods are used to account for these complex geometry and absorption/attenuation affects. Most of these methods use surrogate structures matching the size and shape of the human body, or parts of the body. These "phantoms" so called, are filled with known amounts of the nuclide of interest — or nuclides — if more than one is to be accounted for in the in-vivo measurement. The nuclide, or nuclides, are distributed either throughout the whole structure, or in simulated organ systems in which the activity is assumed, or known, to reside within the subject. Measurement of the activity in the phantom, placed in the same counting position as the subject, will thus yield a calibration constant — usually cpm/unit of activity — that is used to convert the counting rate from the subject into an activity level. Our whole-body phantom, consists of several four litre plastic containers, which we fill with either potassium, for purposes of obtaining a background match for the subject, or with a known amount the isotope of interest, e.g. ^{137}Cs. In other cases we may be interested in measuring the amount of activity in only a part of the body, like the skull. Our skull phantom contains a known amount of ^{210}Pb. We measure this nuclide in the skull to estimate the amount in the whole skeleton as an estimate of the cumulative amount of radon to which the person has been exposed. We also build surrogate structures of the thorax, which include ribs and lungs, for calibrating measurements of insoluble forms of inhaled nuclides which may deposit in the lungs.

Unfortunately, if measurements of widely different body sizes — men, women and children, e.g. — are being made, these methods are prone to error, unless phantoms of several different dimensions are used, especially if the energy of the gamma-rays are low enough to be absorbed differently in different parts of the body.

The absorption coefficient of the ^{137}Cs gamma (662 keV) is approximately the same in bone and soft tissue. Thus in Goiânia, Mr. Nogueira was able to take advantage of one of the oldest in-vivo calibration techniques, the so-called meter-arc. This technique utilises the fact that if a source of activity is far enough away from a detector, the detector may be considered a "point" detector and therefore the count rate in the detector due to the source will be independent of where the activity is located on the arc with respect to the detector. For in-vivo measurements, the subject is placed in a reclining position at a meter from the center of a detector. In this geometry, the distribution of the activity in the body is relatively unimportant since the distance to the detector will be approximately the same from any point on the arc. Obviously, to cover wide ranges of body thickness, the distance should be further than a meter. Nevertheless, even at a meter this is a good geometry to use for non-uniformly distributed or for uniformly distributed nuclides like ^{137}Cs and yields good calibration accuracy over a moderate body size range. Activity must be high however because of the detector distance. This was not a problem at Goiânia.

A new approach to in-vivo calibration is being developed at in-vivo counting facilities — including our lab at New York University, and at IRD here in Rio de Janeiro — which has the possibility of alleviating some of the errors inherent in current calibration techniques. It makes use of a statistical technique called Monte Carlo. To determine calibration coefficients for gamma-ray sources, the Monte Carlo method, as the name implies, offers a means of randomly selecting the known probabilities for the various types of interactions a photon can experience in a given medium — i.e. photoelectric absorption, Compton scattering and absorption, Rayleigh scattering, etc. — starting with the generation of the photon and ending with absorption of its full energy or remnant scattered energy, either in the originating medium, the air surrounding the medium, or as an interaction within a detector. Thus, in essence, it is a means of solving the photon transport equation by randomly selecting the various photon interaction probabilities in all the mediums through which it moves. As can be imagined, there are many interactions possible in any one photon history. Thus to obtain good statistical results, hundreds of thousands of photon histories must be calculated. The method is only now being developed because of the rapid increase in processing speed of even the small desktop computers now available.

For in-vivo calibrations, the medium the photons are generated in, and interact in, is the body — not an actual body, but a mathematically defined volume in space — in which the calculated interactions from the mathematically distributed source photons are produced. I call this medium the "mathematical" phantom. Computer codes are available which will follow the interaction histories from photon generation within the mathematical phantom boundaries, through a secondary or tertiary mathematically defined medium — usually air — to a final mathematical space defined the detector boundary. The EGS4 code, which we are using at NYU, will also develop the detector spectrum, taking into account the detector type and size and the interaction probabilities of those photons whose histories terminate within the detector medium. At NYU, we are utilising geometries developed by magnetic resonance imaging (MRI) to provide the mathematical phantom boundaries of interest, and to determine the various amounts of bone, muscle and fat contained within the boundaries, so as to provide accurate interaction cross-sections. Although our work now involves only selected structures like the skull, others are in the process of developing mathematical phantoms of the whole body. Accurate representation of a whole-body mathematical phantom developed from MRI images of course requires the imaging data from an MRI scan of the whole-body. While not as yet abundantly available, these data are beginning to be developed.

The so-called MIRD phantoms are also being used with the Monte Carlo method to develop whole-body in vivo calibrations. The MIRD phantoms, originally developed to calculate radiation doses to the body from external sources, are a set of mathematically defined volumes resembling the human body which are simplified for purposes of facilitating the calculation. The models are of the whole-bodies of an adult male, female and a child and include estimates of the cross-sections for bone, muscle and tissue in that model. It should be somewhat less difficult to realise an in-vivo calibration with the MIRD mathematical phantom than with MRI images as yet. Use of the latter when available however should result in greater accuracy.

Thus, with the use of a "mathematical" phantom, it will be possible to place the mathematically define phantom in any attitude of geometry relative to the mathematical space occupied by a detector and, by generating photons from a mathematically distributed source — distributed either uniformly or within a defined organ space — obtain a calibration factor without need of any surrogate structures. In addition, since the mathematical boundaries of the phantom space can be altered to account for different body sizes and thickness, calibration factors may be obtained which are tailored to each subject — assuming some knowledge of the subject's lena body and bone mass. Also, the error bounds on the calibration factor as a result of and unknown distribution can be obtained with this method since it is possible to assume various distributions of the nuclide mathematically, within the phantom boundaries.

The evolution of this method should be followed closely because when fully developed and satisfactorily tested, the Monte Carlo method should allow very accurate and individualised in-vivo calibration factors to be obtained regardless of whether the counting system is in a mobile laboratory in the field or a fixed installation. It's use should significantly reduce the errors associated with the measurement of body burdens of accidentally ingested radionuclides — errors which are difficult if not impossible to assess with current calibration techniques.

In conclusion, I think it will be very important for the future to invest at this point in time, both the time and money required to construct a transportable and/or mobile counting laboratory having as wide a range of capabilities as possible and to support the investigation and generation of new and more accurate calibration techniques.

SIMPLIFIED CALIBRATION AND EVALUATION PROCEDURES FOR IMPROVISED WHOLE BODY GAMMA SPECTROMETRY IN EMERGENCY SITUATIONS

XA0054884

I. MALÁTOVÁ, I. BUČINA, D. DRÁBOVÁ, I. ČEŠPÍROVÁ

Centre of Radiation Hygiene,
NIPH, Prague,
Czech Republic

Abstract

SIMPLIFIED CALIBRATION AND EVALUATION PROCEDURES FOR IMPROVISED WHOLE BODY GAMMA SPECTROMETRY IN EMERGENCY SITUATIONS.

A semiconductor gamma spectrometer could be used for the rapid estimation of internal contamination of the people in cases of accidents even when no special calibration for whole body counting is prepared. Generic transfer factors for calculation of the whole body detection efficiency from the 25 cm distant point source detection efficiency are presented. Generic dependence of parameters of power function describing the detector efficiency for point source in 25 cm on the detector relative efficiency given by producer was derived from calibration of 18 detectors with relative efficiency from 1.4% to 62%. Minimum detectable activity for various backgrounds and the uncertainty of the estimate of whole body retention are presented, too.

1. INTRODUCTION

Calibration of the detection systems for whole body counting is a complex task. However, in many cases, especially in emergency situations, the main purpose of whole body counting is to make a quick and possibly realistic estimation of radionuclide intake. In such cases, when an unexpected high internal contamination of professionals or greater groups of population occurs or when there is a suspicion of internal contamination of one or few individuals in a place where no whole body counter is available, a simplified calibration procedure could be employed.

When the contaminant consists of one or more gamma emitting radionuclides, gamma spectrometry by high resolution semiconductor detectors should be preferred for retention measurement. Especially in the cases of accidents, when measurements have to be performed in the field, without proper shielding and with the background affected by the accident, high resolution gamma spectrometry — besides rapid identification of radionuclides in the body — can help to distinguish various contributions to the background, diminishing thus the possibility of mistakes. Use of the same computer codes for the spectra analysis as in any other application is another advantage of semiconductor gamma spectrometry over scintillation spectrometry

Uncertainty due to different body build is less when using high resolution gamma spectrometry than by using a scintillation one, especially when the subject of interest is peak laying on the continuum, originated by a scatter of photons with higher energy. The underlying continuum, enhanced by scatter in the body is subtracted using interpolation between the left and right sides of the peak as in any other spectra which results in the improvement of whole body counting minimum detectable activity (MDA).

2. CALIBRATION FOR WHOLE BODY COUNTING

As optimal for rapid whole body monitoring, a configuration presented in Fig.1a was chosen as the standard position (1). In this position the detector to body midline distance is fairly constant and small enough to ensure good sensitivity. The detectors calibrated in this configuration were detectors with cryostats connected to transportable Dewar, so it was possible to place them in a horizontal position. However, a detector with a vertical cryostat, which is, of course the most often used type for laboratory purposes can be used in this position, too.

During the development of the method a position with the distance of the detector in vertical cryostat from the back of the phantom was 35 cm and the distance of the detector from the seat 30.5 cm approximating thus a position of a bent human body (Fig.1b) at the detector. This configuration could be used as an alternative position.

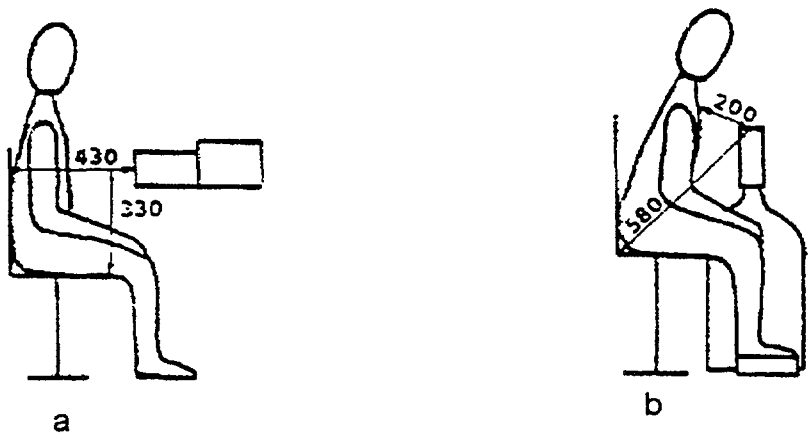


Fig.1 Configuration of measured person in relation to detector. Distances in mm.

Using different detectors and configurations described above, calibrations were performed by a BOMAB phantom filled homogeneously with radionuclide solutions or by a phantom with a slightly different size than a BOMAB, in which vessels with radionuclide solutions were placed to simulate lungs or intestines. Volumes and position of organs in the trunk of phantom were chosen according to. Point source placed in the neck of phantom simulated thyroid. Choice of the simulated organs was done with regard to early contamination. The purpose of the simulation was mainly to estimate the possible under- or overestimation when the radionuclide is rather concentrated in one organ. The suggested standard position is not intended for special thyroid monitoring, the aim of the calibration for thyroid is just to show the possible uncertainties of total body content of radioiodine even with unknown distribution occurring early after intake or after using stable iodine for thyroid blocking.

To estimate approximately the uncertainty due to body constitution, point sources of different energy were placed in the centre of three simple trunk phantoms. They were of elliptical cylinder shape of different thickness, characterised by the "body constitution factor" (CF) 0.4, 0.5 and 0.6, i.e. the ratio of the body mass (kg) to the body height (cm). Measurement was performed with two detectors (20% and 55%).

Another way to estimate uncertainties due to differences in body built and also differences in body position on the seat is the measurements of a BOMAB phantom of a 4 year old child (3) with radionuclides homogeneously distributed in the body. It was measured with two detectors (20% and 38%) and with one of them, also the response to phantom shifting by ± 5cm in both the horizontal and the vertical direction.

3. POINT SOURCE DETECTION EFFICIENCY

Dependence of the full absorption peak detection efficiency $\in_p$ on the photon energy was measured for 18 detectors with relative efficiency $\in_r$ — defined as the ratio of $\in_p$ for 1.33 MeV for a point source of Co 60 measured in 25 cm from the front of a semiconductor detector to the efficiency for the same conditions for the NaI(Tl) detector 7.6cm x 7.6cm, which is 1.2 10^{-3} — declared by producer and ranging from 1.4% to 62%. Besides coaxial HPGe detectors both the p-type and the n-type, one semiplanar LEGe detector and two Ge(Li) detectors were included in the study. For HPGe detectors, also diameter and height of the detectors were given by producer.

The dependence of the detection efficiency $\in_p$ on the energy E in the energy range from 0.15MeV to 2 MeV for photon source 25 cm distance from the detector was expressed as simple power function $\in_p = aE^{-b}$. Parameters a and b were plotted against the relative efficiency $\in_r$ in %. As expected this dependence for a (Fig.2) can be fitted by a straight line and for b on Fig 3 by a power function. For comparison on the statistically less confident parts of the curve are presented two points taken from Helfer (4).

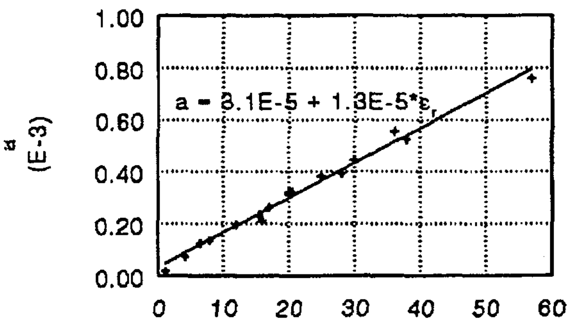


Fig. 2 Experimental and fitted values of the parameter a of power function $e_p = aE^{-b}$ for point source in 25 cm

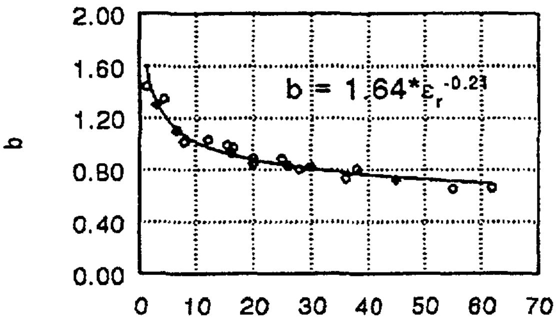


Fig. 3 Experimental and fitted values of the parameter b of power function $e_p = aE^{-b}$ for point source in 25 cm

o experimental values fitted by power function

\+ Helfer's (4) values - not included in fit

4. TRANSFER FACTORS FOR WHOLE BODY COUNTING

As an example the dependence of the detection efficiency $\in_w$ on the photon energy for the human body phantom homogeneously filled with radionuclide solution and for radionuclides in organs together with $\in_p$ for one detector is in Fig 4. Parameters of the power functions fitted to the experimental points being in the range from about 0.2 MeV to 2.0 MeV for 4 detectors are in Table I.

Tab. 1 Whole body detection efficiency $\varepsilon_w = aE^{-b}$

relat.eff. ε_r	h (mm)	d (mm)	position	a (E-4)	b
15%	37	50	standard	0.54	0.81
20%	51.9	49.5	standard	0.84	0.67
55%	84.6	63.3	standard	2:00	0.78
25%	60.6	52.9	alternative	2.15	0.45

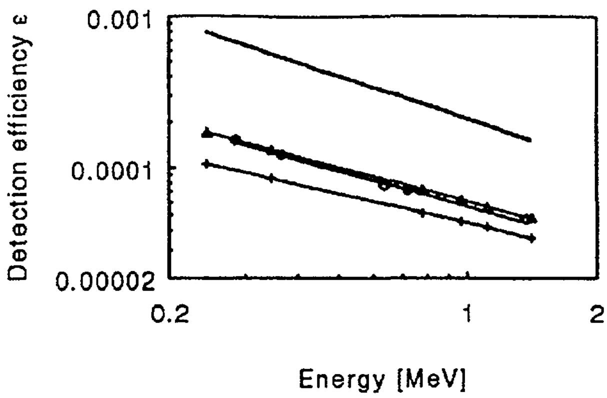


Fig.4 Dependence of detection efficiency on the photon energy for the detector with relative efficiency 15%.
— point source detection efficiency ε_p
o experimental values for whole body calibration ε_w
+ experimental values for lungs
Δ experimental values for intestines

In the standard position (Fig 1a) the ratio of the detection efficiency $\in_w$ to detection efficiency $\in_p$ for different energies can be expressed as a transfer factor h(E) = $\in_w / \in_p$ (Table II).

Tab. 2 Transfer factor η and parameters of fitted power function $\eta = a E^{-b}$

Detector, position	Energy (MeV)						
	0.14	0.36	0.66	1	1.33	a	b
15%,standard	0.2	0.23	0.24	0.25	0.26	0.25	0.12
20%,standard	0.2	0.23	0.25	0.26	0.27	0.26	0.14
55%,standard	0.21	0.21	0.26	0.28	0.3	0.28	0.15
25%,alternative	0.38	0.5	0.5	0.51	0.51	0.51	0.02

Values shown in Table II for three detectors in a standard position are nearly the same since the dimensions of the detectors of the Ge crystal in a detector are negligible in comparison with the source to detector distance and the transfer factor h reflects only the differences due to the mean distance of the radionuclide solution to the detector and self-absorption in the phantom. Thus for the standard position (Fig 1a) the generic transfer factor dependent on energy $\eta(E) = 0.26E^{-0.13}$ was obtained. As a very first estimate the following relation can be used.

$$\varepsilon_w = \varepsilon_r[\%] \times \frac{1.2 \times 10^{-3}}{100} \times 0.25$$

with a resulting maximum overestimation of retention being less than one order of magnitude for energies about 0.2 MeV and by a factor of about 3 for ^{137}Cs. For the alternative position (Fig 1b) the transfer factor is $\eta_a(E) = 0.51E^{-0.02}$. Values are higher than in the standard position not only due to a closer position to the detector but also due to higher efficiency of the used Ge crystal when exposed from the side since the height (h) to diameter (d) ratio of this crystal
h/d = 1.14.

In a similar way transfer factors for organs in a phantom in the standard position were evaluated. In the energy range from 0.14 to 1.33 MeV they varied for lungs from 0.1 to 0.3, for intestines (GIT) from 0.15 to 0.35 and for the thyroid from 0.2 to 0.4. For the alternative position with the detector in vertical cryostat the values were consistently higher.

Calibration curves for whole body counting obtained by the use of suggested generic transfer factor were verified later by the use of calibrations with volunteers who ingested ^{24}Na solution and by comparison of ^{40}K and ^{137}Cs content in the body of a group of people measured with two different detectors (1), good agreement was found.

5. UNCERTAINTY OF ESTIMATED RETENTION

The conservative estimation of uncertainties for a standard position was derived from experiments. Uncertainty due to a person's position in the chair is given by the factor $1.25^{\pm 1}$. From the phantom calibration for organs uncertainty due to non uniform distribution of the radionuclide in the body can be evaluated for the energy range 0.2 to 2 MeV as $1.3^{\pm 1}$, from experiments with the point source in the trunk phantom with variable thickness the uncertainty due to body build is about $1.2^{\pm 1}$. According to our measurement with an HPGe detector ($h/d = 1.14$, $\epsilon_r = 25\%$) and published data on the angular dependence of response (4), the uncertainty due to differences in directional response should not exceed $1.3^{\pm 1}$.

The total impact of all uncertainties, including also uncertainty of the transfer factor, for one measured person as estimated by quadratic summing of relative errors is $1.5^{\pm 1}$. Taking into account a vertical detector with extreme h/d ratio it does not exceed $1.6^{\pm 1}$, being thus more optimistic than our earlier estimate (1).

6. MINIMUM DETECTABLE ACTIVITY

Minimum detectable activities were calculated on the 95% significance level for the detector with $\epsilon_r = 55\%$ and for different background dose rate levels. Standard geometry was used and measuring time 60s was chosen. The lowest background was in the steel shielding of whole body counter, an almost normal background was in the laboratory where some radioactive samples were present. Higher background levels were simulated by the presence of ^{226}Ra, ^{137}Cs, ^{60}Co or ^{60}Co with ^{133}Ba , ^{134}Cs and ^{241}Am sources at different distances from the detector. Thus the dose rate at the place of the detector ranged from 0.02 to 38 µGy/h. In Fig. 5 there is MDA dependence on background dose rates for ^{137}Cs which was not used to arise the background, in Fig.6 is such a dependence for ^{137}Cs where ^{137}Cs peak in the

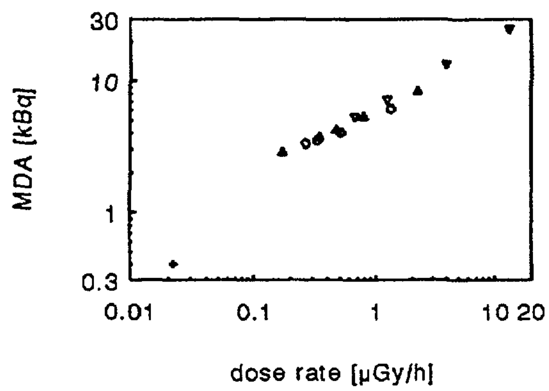


Fig. 5 Minimum detectable activity (MDA) for ^{137}Cs for various background rates
+ background in WBC shielding
Δ background in laboratory
∇ background raised by ^{226}Ra
▲ background raised by ^{60}Co
o backround raised by ^{133}Ba, ^{134}Cs, ^{60}Co, ^{241}Am

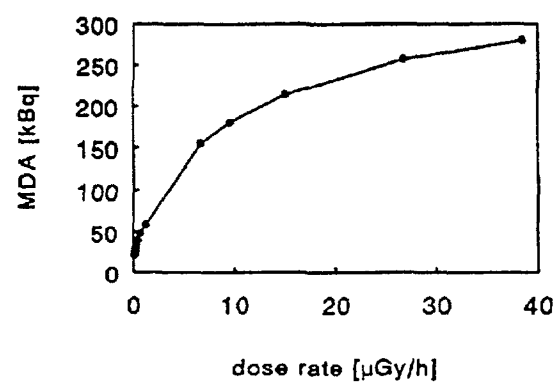


Fig. 6 Minimum detectable activity for ^{137}Cs for background raised by ^{137}Cs

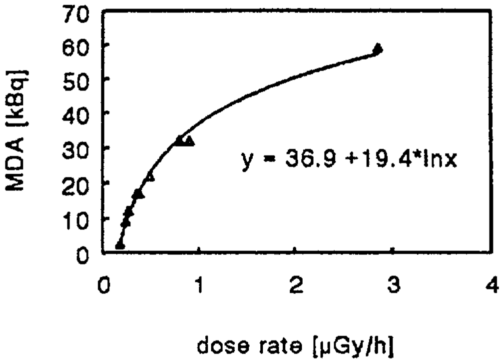


Fig.7 Minimum detectable activity for ^{60}Co for background raised by ^{60}Co

background makes its MDA higher. Similarly in Fig. 7 is the MDA for ^{60}Co for background raised by ^{60}Co.

With a dose rate meter close to the body 50 kBq — used as lower triage action level — can be detected giving the response of 0.05 mGy/h above a normal background, i.e. about +50% (5). However, with a HPGe detector such an activity can be measured in 60 seconds even if the background dose rate is ten times or more the normal value and contains also contributions of the radionuclide of interest.

7. CONCLUSIONS

For the recommended standard position at the germanium detector, generic transfer factors for whole body counting were provided. Also, a generic function for the calculation of the energy dependence of detection from the relative efficiency of the detector was developed. Both factors and functions can be routinely applied. The analysis of uncertainties and minimum detectable activities in enhanced backgrounds proved that the use of the high resolution gamma spectrometry for the measurement of internal contamination in an emergency situation is justified and quality enhancing.

REFERENCES

[1] MALÁTOVÁ, I., et al., Rad.Prot.Dosim., **28** 4 (1989) 291–301.
[2] JOURN. NUCL. MED., MIRD, Suppl.3, Pamphlet 5, August (1969).
[3] KRAMER, G.H., et al., Health Phys., **61** 6 (1991) 893–902.
[4] HELFER, I.K., MILLER, K.M., Health Phys., **55**, 1 (1988) 15–29.
[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Rapid monitoring of large groups of internally contaminated people following a radiation accident, IAEA-TECDOC-746 (1994).

WHOLE BODY COUNTER MEASUREMENTS OF CONTAMINATED PEOPLE IN GOIÂNIA

C.A.N. OLIVEIRA, M.C. LOURENÇO, B.M. DANTAS, E.A. LUCENA
Instituto de Radioproteção e Dosimetria,
CNEN, Rio de Janeiro,
Brazil

G.R. LAURER
New York University Medical Center,
New York, United States of America

Abstract

WHOLE BODY COUNTER MEASUREMENTS OF CONTAMINATED PEOPLE IN GOIÂNIA.

The violation and rupture of a 50.9 TBq (1375 Ci) ^{137}Cs source in the form of caesium chloride salt (CsCl), in Goiânia/Go, Brazil, resulted in a substantially large accident. In order to quantify the internal contamination of the individuals involved, a special whole body counter system, using an 8"x4" NaI(Tl) detector, was developed. The major goal of this counting system, at the initial phase, was to be able to assess the very high level of ^{137}Cs activity in individuals who had direct contact with the radionuclide. The system, initially set up at the Goiânia General Hospital, was adapted to detect a wide range of ^{137}Cs activities. Subjects were required to wear disposable clothing and lie on a reclining, fibreglass chair. Counting time was standardised in 2 minutes (live time) and the minimum detectable activity was 7.3 kBq (197 nCi). Among the people measured, 151 showed ^{137}Cs internal contamination levels ranged from the minimum detectable activity to 78 Mbq (2.1 mCi).

1. INTRODUCTION

Individual monitoring for intakes of radionuclides may be achieved by body activity measurements, excreta monitoring and the combination of the techniques. The choice of measurement technique is determined by several factors: the radiation emitted by the radionuclide, the metabolic behaviour of the contaminant and its retention in the body taking account of both biological clearance and radioactive decay [1].

Due to the large number of people internally exposed to ^{137}Cs and the seriousness of the accident, it was necessary to set up a counting system in the city of Goiânia, so that many people could be measured as quickly as possible. The *in vivo* measurement system had to be designed to measure high levels of ^{137}Cs activity in the body. Whole-body counting (WBC) was attempted for the fourteen patients that were brought from Goiânia to the Navy Hospital in Rio de Janeiro city where an *in vivo* shadow-shield monitoring system was available. However, as foreseen, it was not possible to make a measurement. The activities were far too high for that system, as well as all other existing facilities in the country, which had been designed to measure internal contamination levels just slightly higher than ICRP reference limits [2]. It was necessary therefore to redesign, construct and test a special whole body counting system. This system was appropriate to measure high ^{137}Cs activities.

2. MATERIALS AND METHODS

Aiming to use the *in vivo* bioassay technique to quantify the internal contamination in 29 October, 1987 the design and construction of a whole-body counter system began with specific characteristics, to be installed at the Goiânia General Hospital (GGH), in the city of Goiânia. The GGH was chosen so as to make easier the monitoring of hospitalised patients. These were clinically debilitated due to their acute radiation exposure and were kept isolated. These also were monitored those people that were isolated in the special housing center and those with low contamination levels who were out-patients. The accident involved a large number of people with ages varying from new-born to adult. The caesium body burden varied much from person to person. It was therefore, necessary that the measuring system had a high counting efficiency in order to measure different levels of caesium activity as well as different body sizes. This system was also used to screen internally contaminated people from the Goiânia population. As the number of people measured each day was high, the counting time was an important parameter to be considered in the measurement system.

The system was installed in a 4.0 m width, 3.5 m length and 3.5 m high room, where seven layers of 2 mm thick lead sheets, 2.0 m long and 1.0 m wide were placed on the floor, in layers equidistant from the walls. The walls and ceiling were not shielded. The measurement system consisted of a 20 cm diameter x 10 cm thick NaI(Tl) detector, shielded and collimated by 5 cm of lead, wrapped around the crystal, fastened in an iron framework (2.23 m high, 0.9 m wide, 0.85 m long). The subject was positioned below the detector, lying on a fibreglass chair (like the ones used at swimming-pools). This configuration was close to an arc geometry. The distance from the center of the chair to the geometric center of the detector was 2.03 m. This distance, between the detector and the subject, allowed some advantages over the other WBC described in the literature [3].

One of the difficulties of the system calibration, was to find a ^{137}Cs source with sufficient activity to simulate the real condition of measurement. The available source with high activity was around 1.5 kBq, which was very low to calibrate the system with the distance of 2.03-m from chair to detector. First was used a point source, from the International Atomic Energy Agency (IAEA), reference FH35D — number 50 1717, with an activity of 333 kBq. Later, a ^{137}Cs standard source, with activity of 118 ± 2 kBq, calibrated by the Metrology Department from the Institute for Radiation Protection and Dosimetry (IRD/CNEN), was used in a anthropomorphic phantom to simulate the ^{137}Cs distribution in the body. The source was diluted in a 0.1 N nitric acid solution and distributed uniformly within the phantom in 60 polyethylene bags. Each bag contained approximately 0.25 L of the solution. The bags were placed into an adult-sized phantom, fibreglass mannequin, hollow, thin-walled (3mm) [4]. In order to estimate the background, the same amount of polyethylene bags with 0.1 N nitric acid was put into the phantom. The counting procedures were the same as those applied to the phantom contaminated with ^{137}Cs. The validity of the arc geometry was tested and verified by placing the bags in a smaller, shorter-length phantom. The counting efficiency remained the same, within statistical limits, regardless of the size of the phantom. Thus, using the arc geometry, the same calibration factor could be used for a contaminated infant or a 2 m adult, since the average distance from the center of the crystal of all points along either the adult or child body was the same [5].

The same procedures applied to routine *in vivo* measurements were also applied to the accident subjects, i.e., changing clothes, disposable overshoes, measurement of height and weight, and completion of personal data sheets. Subjects were not required to shower immediately before measurement since daily showering was performed as a rule. However, they were routinely monitored for external contamination using a β counter before whole body counting. In addition, those subjects who had transferable external contamination were decontaminated before counting. [5].

A strong anxiety used to be observed in the subjects during the measurement procedures. Occasionally, the stress caused claustrophobic reactions which results in a delay to start the measurement or a premature end. Efforts were made to minimise these reactions. Frequently, a quick talk with the subject was sufficient to reduce this anxiety, which allowed the measurement to be concluded. Every patients showed a different reaction, and the technical staff responsible for the measurements, had to be always sensitive and alert to these problems. Some special situations used to occur when children were monitored. In these cases, a staff member stayed in the counting room with the child, during the measurement. Afterwards, a second measurement was done without the child.

3. RESULTS AND CONCLUSIONS

From 8 November 1987 to 13 April 1988, 616 people were measured. Among these, 151 presented internal contamination levels above the detection limit.

The range of measured ^{137}Cs activities was 440 times lower than the annual limit of intake (ALI) [2] up to a value of ten times higher than the ALI for ^{137}Cs. The counting efficiency for a child was the same as that of an adult 2-m high. This system showed to be very efficient for *in vivo* measurements. The dead time was lower than 8% for the subject with highest internal contamination, and the minimum detectable activity (MDA) was equal to 9 kBq for a 2 min. counting time ($p < 0.05$) [5].

The measurements had fundamental importance to the study of caesium metabolism, to evaluate the effectiveness of the caesium decorporation therapies, mainly Prussian blue administration, as well as other medical treatments.

In vivo bioassay method for monitoring of internal contamination in emergency situation, has shown to be a valuable tool. The improvised whole-body counter proved to be appropriate for monitoring very high levels of internal contamination. The system attended the necessities for whole body measurements, considering that the work was carried out under sub optimal conditions and necessary time constraints.

REFERENCES

[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Individual Monitoring for Intakes of Radionuclides by Workers: Design and Interpretation, Publication 54, Pergamon Press, Oxford (1987).

[2] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Limits for Intakes of Radionuclides by Workers, Publication 30, Pergamon Press, Oxford, Annals of the ICRP Vol. 2. No. 3/4 (1979).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Directory of whole-body radioactivity monitors, IAEA, Vienna (1970).

[4] MAIELLO, M.L., NETON, J.W., COHEN, N., An inexpensive and multipurpose calibration phantom for *in-vivo* measurements of internal contamination, Health Physics **51** 6 (1986) 809–811.

[5] OLIVEIRA, C.A.N., LOURENGO, M.C., DANTAS, B.M., LUCENA, E.A., Design and operation of a whole body monitoring system for the Goiânia radiation accident, Health Physics **60** 1 (1991) 51–55.

WHOLE BODY MEASUREMENTS FOR IN VIVO MONITORING IN EMERGENCY SITUATIONS

H. DOERFEL
Karlsruhe Nuclear Research Centre,
Karlsruhe, Germany

Abstract

WHOLE BODY MEASUREMENTS FOR IN VIVO MONITORING IN EMERGENCY SITUATIONS.

The conventional procedures for *in vivo* monitoring of γ-emitting radionuclides require a lot of information, such as time and pathway of intake, physical and chemical form of incorporated materials, metabolism etc. In emergency situations this information is rarely available, thus resulting in significant uncertainties for the estimation of intake and committed dose equivalent. Moreover, the procedure is time consuming and thus only a relatively small number of persons can be monitored. In order to cope with these difficulties, a new method for direct internal dosimetry has recently been developed at Karlsruhe Nuclear Research Centre. The method is based on the measurement of the integral photon flux emitted from the body using a special detector system which has been optimised in such a way that the system sensitivity matches the respective dose factors for a maximum number of radionuclides and deposition sites in the body. The detector system consists of four plastic scintillation detectors, which are positioned at the thyroid, at the lungs, under the gastro-intestinal tract and over the thighs of the person monitored in a seated posture. The system allows for detection of effective dose equivalent rates down to 1.6 μSv/week, the mean detection uncertainty being about 200% for known radionuclide mixtures and about 600% for unknown radionuclide mixtures, respectively. The detector system is very easy to handle; the measurement can be performed by untrained individuals and the results are available after a very short measuring time (20 s). Thus, the detector system is appropriate especially for short-term decision making after incidents or accidents. Because of its relative low weight (1 t) the detector system could be installed as a mobile unit in a container for transportation by car, train or aircraft. Thus, in emergency situations the detector system can be brought to the site within a short period of time. It allows for the rapid monitoring of a large number of persons, the accuracy of results in terms of dose equivalent being as good or even better than that of conventional procedures.

1. INTRODUCTION

The conventional procedures for *in vivo* monitoring of γ-emitting radionuclides involve the determination of body or organ burdens using whole body counting techniques and the subsequent estimation of intake and committed effective dose equivalent, respectively. For these procedures information is required with respect to (i) time of intake, (ii) path of intake, (iii) particle size of inhaled aerosols, (iv) chemical solubility and biochemical transportability and (v) metabolism of incorporated materials. In emergency situations this information in general is not available. Thus, the estimation of intake and committed dose equivalent is characterised by significant uncertainties. Besides, it is extremely difficult or even impossible to define general quality criteria such as lower limit of detection or confidence interval for intake and committed dose equivalent, respectively. Thus, it is problematic to define minimum requirements for emergency monitoring devices or to compare different monitoring procedures with respect to the quality of their dose estimates. To overcome these difficulties a new method for direct determination of effective internal dose equivalents has been developed recently at Karlsruhe Nuclear Research Centre. The procedure has special capabilities with regard to routine incorporation monitoring as well as in emergency situations.

2. MEASURING PRINCIPLE

The method refers especially to those radionuclides which commonly are detected with standard whole body counters, i.e. radionuclides emitting γ-rays with relative high abundance (> 10 %) and relative high energy (> 100 keV). If such a radionuclide is deposited in some organ or region of the body, there is a well defined correlation between the photon flux at particular points of the body surface and the dose equivalent rate due to the incorporated radionuclide. This correlation may be used for direct dose assessment with an adequately designed detector system according to the following general equation:

$$H'_{eff}(S) = C(S) \cdot \sum_{i=1}^{n} [\alpha_i \cdot R_i(S)] \qquad \text{with} \qquad C(S) = \frac{\sum_{T} [w_T \cdot SEE(T,S)]}{\sum_{i=1}^{n} [\alpha_i \cdot \varepsilon_i(S)]}$$

$H'_{eff}(S)$ effective dose equivalent rate due to a given radionuclide deposition in the source organ S

$C(S)$ calibration factor of the detector system consisting of n detectors at well defined measuring points for the same deposition in S

$R_i(S)$ response of the detector i for the deposition in S

α_I weighing factor for the detector i ($\sum\alpha_i = 1$)

$SEE(T,S)$ specific effective energy for the source organ S and the target organ T according to ICRP Publication 30

w_T weighing factor for T according to ICRP Publication 30

$\varepsilon_i(S)$ counting efficiency of detector i for the deposition in S

In general the calibration factor C(S) defined by the above equation depends both on the radiation emitted by the radionuclide and on the pattern of the deposition in the body. This dependence, however, can be minimised by adequate optimisation of the detector system, i.e. optimisation of type, number, arrangement, size and lateral shielding of the detectors, material and thickness of radiation entrance windows, electronic settings of amplification and discriminator levels etc.

3. INDOS DETECTOR SYSTEM

The INDOS detector system has been developed both for routine incorporation monitoring and for special monitoring in emergency situations. Thus, the following practical aspects were taken into account:

- The measurement should be performed with a simple counting detector system without spectrometry.
- The measurement should be performed automatically without the need of any trained staff.
- The measuring time should be very short (i.e. ≤ 20 sec), thus allowing for the monitoring of a large number of persons (> 100 persons per day and unit)

The detector system which meets these conditions is shown in Fig. 1. The main components of the system are four plastic scintillation detectors, being positioned in front of the thyroid (detector 1: 6.5 x 6.5 x 10 cm^3), in front of the respiratory tract (detector 2: 16 x 16 x 10 cm^3), over the thighs (detector 3: 20 x 20 x 10 cm^3) and under the gastro-intestinal tract (detector 4: 20 x 20 x 10 cm^3). The detectors are operated by standard electronics consisting of a high voltage power supply, a preamplifier and a main amplifier with a single channel analyser. The detector pulses are fed into four counting channels of a PC for further processing. The PC is connected to a magnetic card unit for input of personal data (i.e. personal identification, body weight, body height, chest circumference) and for output of measuring results. For individual adjustment of the measuring geometry the seat of the detector system can be moved by computer controlled stepping motors in the horizontal and vertical direction according to the subject's body proportions (chest circumference for horizontal movement and body height for vertical movement, respectively). The individual adjustment allows for measurement of all subjects with body heights ranging from 150 cm up to 200 cm.

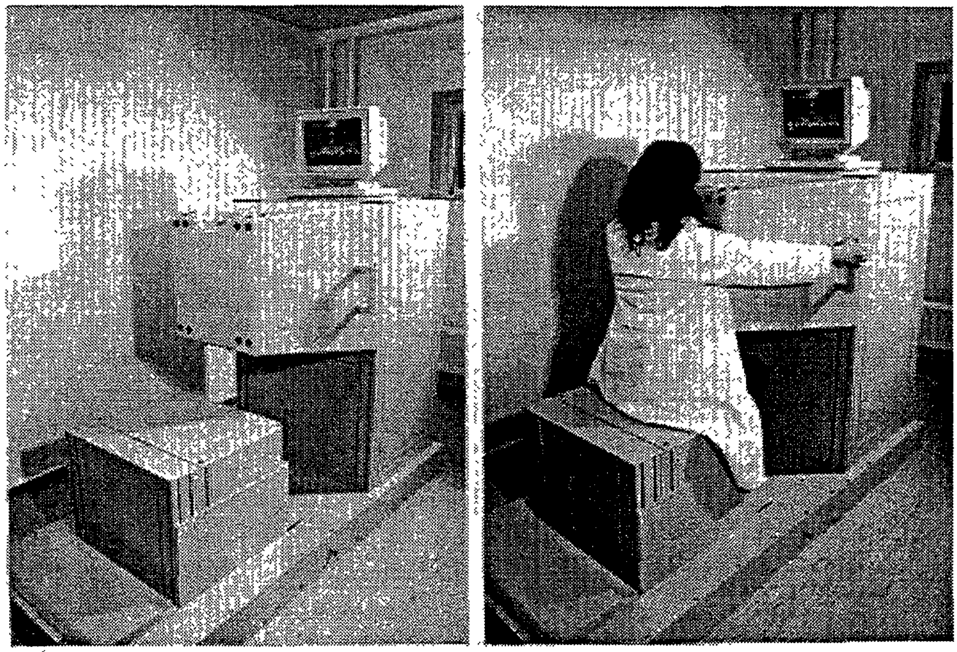


Fig 1: The INDOS detector system

In order to use the detector system for dose estimations in any measuring geometry, a mathematical calibration procedure was applied. This procedure is based on a set of semi-empirical formulas for the calculation of the detector response as a function of the photon energy of the source, the co-ordinates of the source position and of the thickness of the tissue between the source and the detectors. The measurements in general are performed using calibration factors for the reference man having a body weight of 70 kg and a body height of 170 cm. Since the SEE values of ICRP Publication 30 also refer to the reference man, this procedure will yield realistic results for all persons having similar body proportions. Moreover, this procedure will also yield very good results for persons with different body proportions, because the calibration factors and the SEE values show very similar dependence on the body size. Thus, this method of internal dosimetry to some extent has a built-in correction of the body size effects. This is an important advantage of the direct method, especially with respect to those emergency situations where also children have to be measured.

The background counting rate is governed by radiation emitted from the natural radionuclides, i.e. K-40 contained in the materials of the environment of the detector system. The contribution of the natural airborne activity is relatively small and so the background of the detector system is very stable when counting is done subsequently without a subject in the same environment. When counting with a subject, however, the background of all detectors is reduced significantly due to the absorption of the environmental radiation by the body.

The absorption effect has been studied on the basis of more than 300 measurements with about 40 male and 20 female subjects with different body proportions. These measurements show the background counting rates to be in very good approximation of a linear function of the body weight (detector 1 and 4), the chest circumference (detector 2) and the body height (detector 3), respectively. The mean deviation of the measured background counting rates from the respective fit values are ±26 cts/20s (detector 1), ±115 cts/20s (detector 2), ±142 cts/20s (detector 3) and ±140 cts/20s (detector 4), these values being less than twice the standard deviation due to counting statistics.

4. EVALUATION

For evaluation of the measurement, first the individual background counting rates of the four detectors are calculated on the basis of the biometric parameters of the subject. These hypothetical background values are subtracted from the measured counting rates. If the resulting net counting rate of any detector is significantly larger than the respective standard deviation ($> 3.29\sigma$), the net counting rates of all four detectors are analysed with a special logic algorithm in order to select one of the four deposition cases listed in the first column of Table I.

As can be seen from Table I, the measured dose quantities are the effective dose equivalent in the first two deposition cases, the lung dose equivalent in the third deposition case and the thyroid dose equivalent in the fourth deposition case, respectively. The calibration factors and the values for the lower limit of detection refer to Co-60 in the first three cases and I-131 in the last case. For unknown mixtures of radionuclides the choice of these standard calibration factors results in a mean calibration error of about 500%. Otherwise the calibration error amounts to about 200%.

Tab. 1:
Parameters for evaluation of the measurement and corresponding values of the lower limit of detection for one 20 s measurement (95 % confidence level)

Deposition case	Measured dose quantity	Weighing factors ($\alpha_1/\alpha_2/\alpha_3/\alpha_4$)	Calibration factor (µSv/d per cps)	Lower limit of detection (µSv/week)
Homogeneous whole body deposition	Effective dose equivalent	0/0.34/0.33/0.33	0.018	1.6
Inhomogeneous trunk deposition	Effective dose equivalent	0/0.14/0.36/0.50	0.062	6.3
Dose relevant lung deposition	Lung dose equivalent	0/1/0/0	0.072	9.6
Dose relevant thyroid deposition	Thyroid dose equivalent	1/0/0/0	4.7	140

5. CONCLUSIONS

The INDOS detector system offers some advantages which especially in emergency situations may be of great importance:

- The measurement is performed automatically and there is no need for trained staff.
- The measuring time is short and thus a large number of persons may be monitored within a relative short period of time.
- First estimates of the individual effective dose equivalent rate are available immediately after the measurement.
- The direct determination of the dose equivalent in principle is more precise than the conventional procedures for internal dosimetry, because (i) the retention of radionuclides in the body may be measured explicitly and (ii) the dependence of the dose equivalent on the body proportions is corrected implicitly.
- The measuring procedure is comparable to the external dosimetry with respect to accuracy and lower limit of detection. Thus, the results of internal and external dosimetry can be summed up in an easy and reasonable manner.
- The detector system can be installed in any building; it also can be installed as a mobile unit in a car or in a container for long distance transportation by aircraft or train.

Last but not least, the cost for monitoring with INDOS is much lower than for the conventional monitoring procedures using whole body counters.

BIOLOGICAL DOSIMETRIC STUDIES IN GOIÂNIA RADIATION ACCIDENT

XA0054887

A.T. NATARAJAN, F. DARROUDI, M. V/D BERG
J.A. Cohen Institute,
Inter-University Research Institute for Radiopathology and Radiation Protection,
Leiden, Netherlands

V. HADJIDEKOVA, S. VERMEULEN, S. CHATTERJEE, M. GRIGOROVA
Department of Radiation Genetics & Chemical Mutagenesis,
State University of Leiden,
Leiden, Netherlands

F. GRANATH
Institute of Actuarial Mathematics and Mathematical Statistics,
Stockholm University,
Stockholm, Sweden

A.T. RAMALHO
Institute of Radiation Protection and Dosimetry,
IRD/CNEN,
Rio de Janeiro, Brazil

M.P. CURADO
Foundation Leide Das Neves,
Goiânia, Brazil.

Abstract

BIOLOGICAL DOSIMETRIC STUDIES IN GOIÂNIA RADIATION ACCIDENT.

For the initial estimate of absorbed radiation dose, following the Goiânia accident, the frequencies of unstable chromosome exchanges (dicentrics and rings) in blood lymphocytes stimulated in vitro were determined. Using a dose response curve for induction of unstable aberrations following in vitro irradiation with Cs^{137} gamma-rays, dose estimates were made. Several of the victims have been followed up till 1993 and the frequencies of dicentrics have been determined (Ramalho et al., 1994). Using the chromosome "painting" technique, the frequencies of stable chromosomal aberrations (translations) have been determined. The validity of using the frequencies of translocations for retrospective biological dosimetry of past radiation exposures has been examined and the results are presented.

1. INTRODUCTION

In the Goiânia radiation accident, which occurred in 1987, more than 50 individuals were exposed to moderate to high doses of gamma radiation (IAEA, 1988). Biological dosimetry based on frequencies of unstable chromosome exchanges in peripheral blood lymphocytes was used to estimate the absorbed dose immediately following the discovery of the accident (Ramalho et al., 1988). Cytogenetic follow-up studies have been carried out at different intervals following the accident (Ramalho et al., 1990, Natarajan et al., 1991). Fluorescent in situ hybridisation (FISH) technique employing chromosome specific DNA libraries to "paint" individual human chromosomes (Pinkel et al., 1986) to detect stable chromosome aberrations such as translocations has been used (Natarajan et al., 1991 and 1992). This technique allows easy detection of chromosomal translocations in peripheral lymphocytes of irradiated individuals (Natarajan, et al., 1991, Lucas et al., 1992). Recently, the possibility of using translocation frequencies for estimating radiation doses of past exposures has attracted much attention (Lucas et al., 1992). For example, the frequencies of translocations in atom bomb survivors seem to be related to the ones which were expected on the basis of in vitro generated dose response curves for the calculated doses (TD 86) during the accident (Lucas et al., 1992). However, in the same study, no good correlation between the present day frequencies of translocations to the calculated doses in the victims of a reactor accident in Oak Ridge,1968, was found. Since we had determined the initial frequencies of dicentrics in the victims of the Goiânia accident, this cohort offers the possibility check (a) the relationship of the current frequencies of translocations to the initial frequencies of dicentrics found, and (b) whether the current frequencies of translocations can be used to estimate retrospectively doses of radiation exposure in the past.

2. MATERIAL AND METHODS

From the victims as well as from healthy volunteers blood samples were collected in heparinized tubes and transported to Rio de Janeiro and Leiden. Whole blood cultures were set up. After 48h. incubation at 37^0C, the lymphocytes were fixed and processed for chromosome analysis by routine procedures. In the follow-up studies, the medium contained 10 :M 5-bromo-deoxy-uridine, which allowed identification of second division cells. Slides were stained with 5% aqueous Giemsa solution and the cells were scored for the presence of dicentrics, rings and fragments. The slides to be processed for FISH were stored at -20^0C. Slides aged one week were used for in situ hybridisation. Chromosome specific DNA libraries cloned in phase or blue scribe plastids were amplified, purified and biotynilated by nick translation. In situ hybridisation was carried out as described earlier (Pinkel et al, 1986, Natarajan et al, 1991, 1992). Under standard conditions, 1 :g of biotin labelled DNA representing the library of a cocktail of two, three or four chromosomes was combined with competitive DNA followed by denaturation, then hybridised in situ (over night at 37^0C) with the cytological preparation. The slides were washed successively in 50% formamide/2 X SSC (42^0C), 0.1 x SSC (60^0C) and 4 X SSC/0.05% Tween 20, at pH 7.0 at room temperature. The slides were incubated in 5% natural non-fat dry milk for 15 min. at room temperature. Detection of biotinylated probe was achieved by using Avidin-FITC. Amplification of signals was made by reincubation with biotin conjugated anti-avidin D antibody for 30 min. at room temperature followed by another incubation with avidin-FITC. The slides were mounted with antifading reagent (Vectaschield H-1000) and propidium iodide as the counter stain. The following cocktails were used representing different proportions of the human genome (in parenthesis). 1, 3, 4,& X (25.8%), 8 & 15 (7.9%), 6, 7 & 16 (13.7%), 10, 17 & 20 (9.3 %), 17 & 21 (4.3%), 12, 16 & 22 (8.9%) and 2, 10, 13 & 19 (17.7%). These chromosomes represent in total about 79.3% of the genome. Totally more than 50,000 cells were scored for the presence of translocations.

3. RESULTS AND DISCUSSION

The frequencies of dicentrics and rings found immediately after the accident and the estimated doses have been published (Ramalho et al., 1988). The follow up studies indicated a decline in the frequencies of dicentrics with time. From the disappearance of lymphocytes carrying dicentrics with time one can estimate the average mean life time of lymphocytes in the human body. The results obtained from the Goiânia accident indicated, in contrast to earlier values published in the literature, that apart from a small fraction of long lived cells, the mean life time of lymphocytes is in the range 95 to 220 days (Ramalho et al., 1990, Ramalho et al., 1994).

The frequencies of translocations using FISH technique was started in 1989, in which translocations involving chromosome # 2 or #18 were evaluated (Natarajan et al., 1991). It became obvious that it was insufficient to stain a small part of the genome especially at low doses. Therefore, in later studies cocktails of three or more chromosomes were used to evaluate the frequencies of translocations. Meanwhile, the possibility of using translocation frequencies for estimating past radiation exposures was proposed (Lucas et al., 1992), based on the study of A-bomb survivors. The Goiânia accident provides an ideal situation to check the utility of translocations to estimate retrospectively past exposures, as we had estimated doses based on dysenteric data. Since, it has been found that different human chromosomes participate differently in the formation of translocations (Grigorova et al., 1994, Knehr et al, 1994), we used seven different cocktails of chromosome specific libraries to cover about 80% of the genome. The frequencies of translocations for the whole genome were calculated. The results on the frequencies of dicentrics as determined in 1987 and the frequencies of translocations calculated for the whole genome determined in 1993 are presented in Fig. 1.

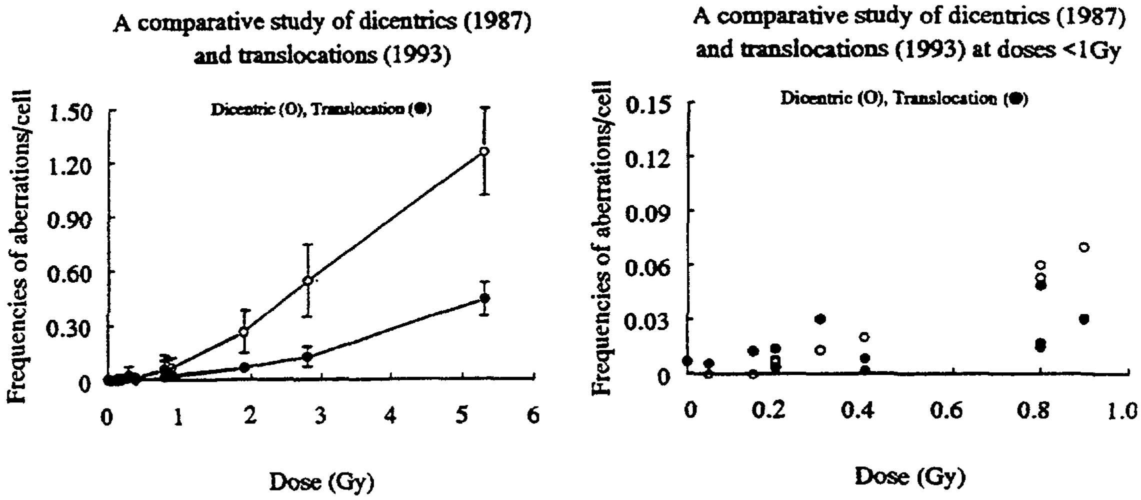


FIG. 1.

The translocation frequencies have been fitted as a function of estimated dose with the linear-quadratic dose response model for the total data set as well as for individuals with doses less than 1 Gy. When the data are restricted to dose <1 Gy, all three models, i.e., linear, quadratic and linear-quadratic fit equally well and cannot be distinguished from each other. From the regression parameters calculated, a significant correlation between translocation frequencies and estimated doses in the low dose region can be observed.

It is assumed that dicentrics and translocations are induced in equal frequencies following irradiation of human lymphocytes. This may be true for reciprocal translocations. However, it has been established now, that other types of translocations, i.e., terminal, interstitial and complex ones do occur and that the frequencies of translocations are more than dicentrics (Natarajan et al., 1992, Schmid et al., 1992). The occurrence of complex translocations is dose dependent and increases with the dose. At low doses, < 1 Gy, it is expected that such translocations are rare. Though most of the translocations observed in this follow-up study were reciprocal or terminal, some interstitial translocations were also encountered. Assuming equal frequencies of translocations and dicentrics, one can analyse the present data for the validity of such a relationship between dicentrics observed in 1987 and the translocations observed in 1993. These ratios are presented in Table I.

Based on the overall test, pooling all individuals, the hypothesis "equal frequencies of dicentrics and translocations" can be rejected at a very high significance level ($p<0.0001$). This hypothesis can also be significantly rejected ($p<0.001$) in the case

Table 1. Test for equality between frequencies of dicentrics-87 and translocations-93

Estimated dose(Gy)	ratio between freq. dics/trans	(95% confidence interval)	signficance level *HO: fr.dic/fr trans = 1*
5.3	2.87	2.33-3.55	p<0.001
2.8	4.39	2.99-6.60	p<0.001
1.9	4.20	2.67-6.59	p<0.001
1.9	3.87	2.58-5.80	p<0.001
0.9	2.33	1.23-4.41	p<0.01
0.8	3.56	1.80-7.07	p<0.001
0.8	3.62	1.33-9.60	p<0.05
0.8	1.24	0.42-3.08	n.s.
0.4	2.40	0.41-16.37	n.s.
0.4	10.52	1.04-513.1	p<0.05
0.3	0.44	0.09-2.22	n.s.
0.2	0.58	0.06-2.41	n.s.
0.2	1.90	0.14-26.27	n.s.
0.15(<0.2)	0	0.09-2.2	n.s
0.05(<0.1)	0	0-2.16	n.s.

Exact confidence intervals have been calculated when any of the number of dicentrics or translocations scored are less than 10, otherwise a normal approximation has been applied.

when only doses <1 Gy are considered but this significance is due to individuals receiving estimated doses of 0.8–0.9 Gy. As can be seen in the Table I, the majority of individuals display significant differences in frequencies of dicentrics and translocations. The ratio between the frequencies of dicentrics and translocations seems to be about 3, a factor which seems to be dose dependent, since the ratios are significantly lower for at least two individuals with low doses compared to a few with high doses.

From these results, it is obvious that we cannot directly extrapolate from translocation frequencies to initial dicentric frequencies and ensuing estimates of absorbed doses. One can use a correction factor, which appears to be dose dependent and further work is needed for arriving at a reliable correction factor. Unfortunately, no initial translocation data are available. Assuming that the initial frequency of dicentrics and translocations are equal, it is obvious that cells carrying these two types of aberrations decay with different half lives. There are several factors which contribute to the differential reduction in the frequencies of translocations vs. dicentrics with time, which include the following:

a) While dicentric carrying lymphocytes detected in 1993 were exposed originally in 1987 and are long lived, the translocation carrying lymphocytes in addition to long lived ones, can originate from irradiated stem cells,

b) The stem cell population during exposure, contains cells at different cell cycle stages and those in G1 phase will only respond with dicentrics and translocations. At high doses cells containing both dicentric and translocation will be eliminated in further divisions,
c) It is not known as to whether G1 precursor stem cells are equally or more sensitive to radiation for induction of exchange aberrations,
d) Radiation induced apoptosis can play a role in the elimination of aberration carrying cells,
e) There are several types of T lymphocytes with different life spans. At least two prominent ones are known, having mean life spans of 1.1 and 6.3 years (Bogen, 1994). The disappearance of lymphocytes carrying dicentrics in Goiânia victims also points out to the existence of two such populations of T lymphocytes (Ramalho et al., 1994),
f) The existence of different classes of lymphocytes with differences in radiosensitivity may lead to elimination of sensitive cells,
g) Though many types of complex translocations are induced by ionising radiation, especially at high doses, not all of them are transmissible, and only 20 to 30% of them can pass through cell division (Savage, 1994) .

4. CONCLUSIONS

Our data indicate that from the frequencies of translocations one cannot directly estimate past exposure doses retrospectively, though this can be achieved by using a correction factor. This method appears to be more valid for low doses (<1 Gy) than for higher doses.

ACKNOWLEDGEMENTS

We acknowledge Prof. Lars Ehrenberg for his valuable suggestions and interest in this study and Commission of European Communities for partial financial support (F13PCT920017).

REFERENCES

[1] BOGEN, K.T., Int. J. Radiat. Biol., 64 (1994) 195–204.

[2] GRIGOROVA, M., GRANATH, F., NATARAJAN, A.T., Int. J. Radiat. Biol. (submitted) (1994).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, IAEA STI/PUB/815, Vienna (1988) 132 pp.

[4] KNEHR, S., ZITZELSBERGER, H., BRASELMANN, H., BAUCHINGER, M., Int. J. Radiat. Biol. **65** (1994) 683–690.

[5] LUCAS, J.N., AWA, A , STRAUME, T., POGENSEE, M., KODAMA, Y., NAKANO, M., OHTAKI, K., WEIER, H.U., PINKEL, D., GRAY, J., LITTLEFIELD, G., Int. J. Radiat. Biol. **62** (1992) 53–63.

[6] NATARAJAN, A.T., VYAS, R.C., WIEGANT, J., CURADO, M.P., Mutation Res. **247** (1991) 103–111.

[7] NATARAJAN, A.T., VYAS, R.C., DARROUDI, F., VERMEULEN, S., Int. J. Radiat. Biol. **61** (1992) 199–203.

[8] PINKEL, D., STRAUME, T., GRAY, J.W., Proc. Natl Acad. Sci. (USA), **83** (1986) 2934–2938.

[9] RAMALHO, A.T., NASCIMENTO, A.C.H., NATARAJAN, A.T., Radiat. Protect. Dosimetry, **25** (1988) 97–100.

[10] RAMALHO, A.T., NASCIMENTO, A.C.H., BELLIDO, P., In Chromosomal Aberrations- Basic and Applied Aspects, (OBE, G., NATARAJAN, A.T., Eds.) Springer Verlag, Heidelberg (1990) 224–230.
[11] RAMALHO, A.T., CURADO, M.P., NATARAJAN, A.T., Mutation Res. (submitted) (1994).
[12] SAVAGE, J.K., Clinical Cytogenetics Bull. (in press) (1994).
[13] SCHMID, E., ZITZELSBERGER, H., BRASELMANN, H., GRAY, J.W., BAUCHINGER, M., Int. J. Radiat. Biol. **62** (1992) 673–678.

SIX YEARS OF CYTOGENETIC FOLLOW-UP OF UNSTABLE CHROMOSOME ABERRATIONS IN GOIÂNIA PATIENTS

XA0054888

A.T. RAMALHO
Institute of Radioprotection and Dosimetry,
National Commission of Nuclear Energy,
Rio de Janeiro, Brazil

M.P. CURADO
Fundação Leide Das Neves Ferreira,
Goiânia, Brazil.

A.T. NATARAJAN
MGC, Department of Radiation Genetics and Chemical Mutagenesis,
State University of Leiden, Sylvius Laboratories,
Leiden, Netherlands

J.A. COHEN
Interuniversity Research Institute of Radiopathology and Radiation Protection,
Leiden, Netherlands

Abstract

SIX YEARS OF CYTOGENETIC FOLLOW-UP OF UNSTABLE CHROMOSOME ABERRATIONS IN GOIÂNIA PATIENTS.

Following the radiological accident which occurred in the city of Goiânia (Brazil), in September of 1987, a cytogenetic follow-up of 16 exposed patients was started, aiming to observe the mean life time of lymphocytes containing dicentric and ring aberrations. The results suggest that for the highly exposed individuals (doses above 1 Gy) the disappearance rate of unstable aberrations follows a two-term exponential function. Up to 470 days after exposure, there is a rapid fall in the aberration frequency. After 470 days, the disappearance rate is very slow. These results may reflect different subpopulations of human lymphocytes, with different life spans.

The estimated average half-time of elimination of dicentrics and rings among the highly exposed group (doses above 1 Gy) was 140 days for the initial period after the exposure (up to 470 days). This value is significantly shorter than the usually accepted value of 3 years reported in the literature. For the individuals who had received less than 1 Gy the disappearance of aberrations seems to have occurred in a slower way.

Mean disappearance functions of unstable chromosome aberrations were inferred, to be applied in accident situations in which there is a blood sampling delay.

1. INTRODUCTION

The persistence of unstable chromosomal aberrations in peripheral lymphocytes have been used to estimate the life span of human lymphocytes *in vivo* (Norman *et al.*, 1965; Buckton *et al.*, 1967; L Jonard *et al.*, 1988). A lymphocyte containing a dicentric or centric ring have a probability around 50% of surviving a mitosis (Savage, 1975). Thus the decay in the frequency of dicentrics and centric rings, measured along the time, can give an estimate of the intermitotic time of the lymphocytes (the mean time spent in G_0).

An extensive cytogenetic follow-up of a group of patients after partial body radiotherapy, during more than 30 years, lead to the estimate that the lymphocyte mean life time is 1600 days, with a corresponding half-life of 3 years (Buckton *et al.*, 1967). In such a study, the lymphocyte life time was estimated in the period between 1400 and 3400 days after exposure, despite a rapid fall in the frequency of chromosomal aberrations during the initial period of the follow-up.

In another study, performed by L Jonard *et al.* (1988) during 21 years in an individual irradiated in 1965 with an average whole-body dose of 5 Gy of gamma rays and neutrons, the mean lymphocyte life time was also estimated to be 1600 days. Nevertheless, the first blood sample was collected 9 months after the exposure. Recently, Lucas *et al.* (1992) estimated in 3.8 years the half-life of the lymphocytes of a woman who, in 1985, incorporated tritiated water, receiving a whole body dose of 0.4 Gy. In another recent study (Michie *et al.*, 1992), the mean T lymphocyte half-life calculated from their data was 730 days.

In September of 1987, a radiological accident occurred in the city of Goiânia (Brazil), in which a 50.9 TBq (1375 Ci) ^{137}Cs radiotherapy source was broken in pieces, leading to exposure, internal and external contamination of individuals, as well as environmental contamination. In order to assess the absorbed radiation doses of individuals involved in the accident, peripheral blood lymphocytes of more than a hundred persons were scored for unstable chromosomal aberrations, through the technique of cytogenetic dosimetry (Ramalho *et al.*, 1988, 1990). Description and details of the accident, medical consequences and clinical management of the patients are fully described elsewhere (IAEA, 1988; Brandno-Mello *et al.*, 1991).

During the emergency period of the Goiânia accident, a cytogenetic follow-up of some of the patients (16 in total) was started to observe the disappearance rate of unstable chromosome aberrations. Blood samples from those 16 patients were recollected and scored for chromosome aberrations during a period of 6 years. The main objectives of our follow-up were to study the life span of human lymphocytes and estimate suitable correction factors to be applied to an observed frequency of chromosomal aberrations, if a delay in blood sampling has occurred.

2. MATERIAL AND METHODS

Blood samples from 16 patients exposed during the Goiânia accident were re-examined at different sampling times after the exposure (from 30 to 2180 days). From the 16 patients, 9 had received more than about 1 Gy and 7 less than this.

Almost all of them had some levels of internal contamination by ^{137}Cs, as estimated by colleagues in the Division of Internal Monitoring using radioactivity measurements in urine and faeces or whole-body counting (Lipsztein *et al.*, 1991). The level of internal contamination could alter the decay in the frequency of chromosomal aberrations, as it is known that incorporated Cs distributes uniformly throughout the body, mainly in muscle. Of the 16 selected patients, 14 had low to moderate degrees of internal contamination, thus their estimated absorbed doses were due mainly to exposure. We also included 2 patients with high Cs body burdens to observe this possible effect.

The experimental methodology used for the chromosome analysis during the follow-up was exactly the same used for the first dose estimates (Ramalho *et al.*, 1988). From each individual, a 10-mL peripheral blood sample was collected in a heparinized vacutainer. The erythrocytes were sedimented by centrifugation, and 2 ml of the buffy coat rich in leukocytes was collected and added to 10 ml of Ham's F-10 medium supplemented with foetal calf serum (25%) and 0.2 ml of phytohemagglutinin (Murex). The cultures were incubated for 48 h, and 0.04 mg of colchicine (Sigma) was added 2 h before harvest. After hypotonic treatment with KCl (0.075 M) for 15 min., the lymphocytes were fixed in methanol-acetic acid (3:1) and dropped onto clean, cold, wet slides. The slides were stained with aqueous Giemsa stain solution.

The number of metaphases scored per sample depended on the observed frequency of unstable chromosomal aberrations. At the beginning of the follow-up, when the aberration frequencies were high, 100 to 200 metaphases were enough. Later on, the number was increased to about 400 to 500 metaphases per sample, as the observed frequencies decreased.

3. RESULTS AND DISCUSSION

The individual data of elimination of dicentrics plus rings show that for the highly exposed subjects (doses above 1 Gy) there was a rapid fall in the frequency of aberrations during the first 470 days after exposure, followed by a much slower elimination of aberrations, almost non-existent. Therefore, for the highly exposed subjects, the disappearance of unstable aberrations seems to have followed a two-term exponential function, with a short term (in the initial phase, up to 470 days) and a long term, after 470 days of follow-up. Only the data of the short term was fitted to a simple exponential function.

The objective of this fitting was to obtain the individual rates of disappearance of unstable aberrations and, from them, the individual half-times ($T_{1/2}$=0.693/b). The mean life time of lymphocytes with unstable aberrations can be estimated using $1/b$.

In order to evaluate the influence of biological parameters in the half-time of elimination of lymphocytes bearing unstable aberrations, a multiple regression for independent variables was performed. The biological parameters tested were sex, age, level of leukopenia shown during the critical period of the accident, initial frequency of chromosomal aberrations (represented by coefficient a) and the administration of rHuGm-CSF (recombinant human granulocyte macrophage colony stimulating factor) during the course of the first month after exposure. This drug was given as a continuous intravenous infusion in a daily rate of 500 mg.m^{-2} (Brandno-Mello *et al.*, 1991).

In the present work, leukopenia was considered moderate for lymphocyte counts below normal but above 2000/mm^3 and severe below 2000. Leukopenia occurred during the first weeks after exposure. At the end of the first month, almost all patients had already recovered from bone marrow aplasia or hypoplasia and showed normal blood cell counts. None of the biological parameters showed correlation with the half-times of elimination of unstable aberrations. The mean half-time of elimination of dicentrics plus rings for the initial period of the follow-up (up to 470 days) was 140 days for the 9 highly exposed subjects who received doses higher than about 1 Gy.

We do not have many experimental points from the subjects with doses lower than 1 Gy, thus it was not possible to observe a short term in the data of those subjects, if one exists. For them, the disappearance of aberrations seems to have occurred in a slower way. For the less exposed group, the half-lives were not estimated, due to the lack of data in the period in question.

Two subjects had a high body burden of internal contamination by ^{137}Cs. For them, the initial frequency of aberrations first increased, in reasonable agreement with the estimated doses due to the internal contamination, as calculated by colleagues. Later on the frequencies began to fall, following the decorporation of ^{137}Cs.

One of the purposes of the present work was to deduce a correction factor to be applied in accident cases when there is a delay between exposure and blood sampling. With this purpose, two situations were considered, as follows:

In the first situation it is suggested a correction function when the delay is not very long (up to 470 days). As the data for the highly exposed group indicates that there is no correlation between the half-time of disappearance of aberrations and the initial frequency of aberrations, we can assume that an individual half-time of elimination of unstable aberrations is equal to the mean value of 140 d. Therefore, we suggest this mean value of 140 d for the half-time, to be applied to a simple exponential function, whenever it is desirable to correct an observed frequency of aberrations, as long as the elapsed time is known and there is an approximate idea of the dose received, which must be higher than about 1 Gy. If the dose received is supposed to be less than 1 Gy, we do not suggest any correction factor, because of the lack of enough data.

In the second situation it is suggested a correction function when the delay is very long, superior to 470 days. After this period, the frequencies of unstable aberrations reach a value approximately constant, corresponding to the long term observed in the highly exposed patients. In order to observe if there would be a correlation between the final and initial frequencies of aberrations, for all subjects investigated (low and high doses), a linear correlation was fitted. The term "final frequency" represents the mean frequency observed after 470 days, included. The coefficient of correlation (r) between the initial and final frequencies is 0.87 ($p<0.05$). We suggest this linear function ($Y = ax$, where $a = 10.02$) as the correction factor for an observed frequency of unstable aberrations, for all ranges of dose, whenever the elapsed time is longer than 470 days, and up to about 6 years, period of time that lasted this follow-up. This means that one can simply multiple by 10 an observed frequency of unstable aberrations to obtain the approximate original one.

The two components (short and long terms) observed in the kinetics of the disappearance of aberrations may be explained by the existence of different subpopulations of T lymphocytes, with different life spans. The lifetime of the lymphocyte would be related to the antigen to which the lymphocyte is specific to respond to (if a rare or common one), since the lymphocyte will be stimulated to enter mitosis when in contact with the appropriate antigen. Long-lived lymphocytes would, therefore, be the ones committed with rare antigens. It is possible that PHA stimulates all the lymphocytes already committed to respond to any antigen, which would include the short and long-lived ones. It is possible that some lymphocytes remain *in vivo* without dividing for the life time of the individual if he is not exposed again to the particular antigen to which the lymphocyte is specific to. This hypothesis has already been presented by Buckton *et al.* (1967) and favours the concept of the lymphocyte as the immunological memory of the body, because of its potential for very long survival *in vivo*.

ACKNOWLEDGEMENTS

This project was partially supported by the International Atomic Energy Agency (Vienna) and by the European Economic Community (Radiation Protection Program). We also thank Drs. Joyce L. Lipsztein, Helvécio Mota and C.E. Brandno-Mello, from CNEN (Brazil).

REFERENCES

[1] BRANDÃO-MELLO, C.E., OLIVEIRA, A.R., VALVERDE, N.J., FARINA, R., CORDEIRO, J.M., Clinical and haematological aspects of ^{137}Cs: the Goiânia radiation accident, Health Physics, **60** 1 (1991) 31–39.

[2] BUCKTON, K.E., COURT BROWN, W.M., SMITH, P.G., Lymphocyte survival in men treated with X-rays for ankylosing spondylitis, Nature, **214** (1967) 470–473.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological accident in Goiânia, IAEA, Vienna, STI/PUB/815 (1988).

[4] LÉONARD, A., DEKNUDT, G., LIONARD, E.D., Persistence of chromosome aberrations in an accidentally irradiated subject, Radiat Prot Dosm., **22** 1 (1988) 55–57.

[5] LIPSZTEIN, J.L., BERTELLI, L., MELO, D.R., AZEREDO, A.M.G.F., JULIÃO, L., SANTOS, M.S., Application of *in-vitro* bioassay for ^{137}Cs during the emergency phase of the Goiânia accident, Health Physics **60** 1 (1991) 43–49.

[6] LUCAS, J.N., POGENSEE, M., STRAUME, T., The persistence of chromosome translocations in a radiation worker accidentally exposed to tritium, Cytogenet Cell Genet. **60** (1992) 255–256.

[7] MICHIE, C.A., MCLEAN, A., ALCOCK, C., BEVERLEY, P.C.L., Lifespan of human lymphocyte subsets defined by CD45 isoforms, Nature **360** (1992) 264–265.

[8] NORMAN, A., SASAKI, M.S., OTTOMAN, R.E., FINGERHUT, A.G., Lymphocyte life time in women, Science, **147** (1965) p. 745.

[9] RAMALHO, A.T., NASCIMENTO, A.C.H., NATARAJAN, A.T., Dose assessments by cytogenetic analysis in the Goiânia (Brazil) radiation accident, Radiat Prot Dosm., **25** (1988) 97–100.

[10] RAMALHO, A.T., NASCIMENTO A.C.H., BELLIDO, P., Dose estimates and the fate of chromosomal aberrations in Caesium-137 exposed individuals in the Goiânia radiation accident, (OBE, G., NATARAJAN, A.T., Eds.), Chromosomal Aberrations, Basic and Applied Aspects, Springer-Verlag, Heidelberg (1990) 224–230.

[11] SAVAGE, J.R.K., Classification and relationships of induced chromosomal structural changes, J. Medical Genetics, **12** (1975) 103–122.

THE EARLY MEDICAL RESPONSE TO THE GOIÂNIA ACCIDENT

N.J. VALVERDE, A.R. OLIVEIRA
Laboratory of Radiological Sciences,
University of the State of Rio de Janeiro,
Rio de Janeiro, Brazil

XA0054889

Abstract

THE EARLY MEDICAL RESPONSE TO THE GOIÂNIA ACCIDENT.

The Goiânia accident was the most severe radiological one that ever happened in the western hemisphere. The response to its human, social, environmental, economical and psychological burdens represented a huge challenge. Thanks to a multi-institutional intervention the consequences of the accident were greatly minimised. The medical response followed the same pattern and was based on a three-level system of progressive assistance.

The early medical response encompassed medical and "radiological" triage, admission to a specially prepared ward of a local hospital and treatment at a reference center in Rio de Janeiro.

1. INTRODUCTION

The use of technology brings together risks to human beings and to the environment as a whole. Risk has become an important subject of discussion and uneasiness [1].

Industrial risk is not confined within the limits of an industrial plant, so that public concern include not only ionising radiation, but also asbestos, chemical and non-ionising radiation, as microwaves and electromagnetic fields [2-3].

The preparedness to respond to major accidents either natural or industrial, must take into account the public perspective too and radiation is such a good example. Indeed, this represents a real challenge, even in developed countries[4], as it has been demonstrated in many circumstances[5]

Although immediate deaths in Chernobyl and in Goiânia were modest if compared to Bhopal and San Carlo de la Repita[5], for instance, the immediate and late consequences of those accidents were greatly increased in the public judgement, making the medical and general responses even more difficult.

The description of the accident can be found elsewhere[6-7], but it is worth mentioning that as the 50.8 Tbq 137-Cs source was dismantled and minute fragments were distributed to several individuals and families, a significant number of persons were affected. From 13 to 28 September 1987 112,800 persons were triaged by the medical and radiological teams at a football (soccer) stadium. Table I summarises the immediate medical impact.

TABLE I. THE IMMEDIATE MEDICAL IMPACT

Medical and radiological triage	112,800
Internal/external contamination	129
Hospital admission	20
Acute radiation syndrome (death)	8 (4)

2. THE EARLY MEDICAL RESPONSE

As soon as the accident was recognised by the Brazilian National Nuclear Energy Commission (CNEN) a number of professionals were summoned to Goiânia (most with CNEN, FURNAS — the largest Brazilian power utility and the Navy). Three of them were physicians specialising in Radiation Medicine whose immediate tasks were to triage victims, to deliver first aid and conventional therapy and to decontaminate, both internally and externally. This mission was accomplished on a round the clock basis and very difficult, not only because at the magnitude of the emergency, but also in virtue of a strike of health personnel in Goiânia. Besides, "radiophobia" precluded any initial help to the attending physicians. The severity of some medical conditions and associated psychological disturbances were additional difficulties[8-9-10].

The medical response was based on a three-level system in accordance to the standard "Facilities and Medical Care for On-Site Nuclear Power Plant Radiological Emergencies" by the American Nuclear Society[11] that is adopted by FURNAS at its Angra dos Reis Nuclear Power Plant.

Medical care was delivered at each of the levels in accordance to the severity of the skin injuries, the contamination burden and the degree of bone marrow depression, as next described.

a) The FIRST LEVEL took place at the OLYMPIC STADIUM in Goiânia and consisted of the medical evaluation of the victims, considering their triage and reference to another level of assistance. In such a way, not only the observation of local (skin) injuries and external counting through portable monitors were useful tools, but also the existence of any of the prodomal manifestations of the acute radiation syndrome — ARS (nausea, vomiting, anorexia, etc.). Also clinical and laboratory findings, like alopecia and low blood counts, helped in determining the destiny of the patients.

Those with external contamination were decontaminated using neutral warm water lavage with neutral soap. Reassurance of individuals with minor or no exposure or contamination was a procedure at this level.

An extension of the first level was the INSTITUTE FOR THE PROTECTION OF MINORS (FEBEM), used on an out-patient basis for those who had had only minor external or internal contamination, but who had their houses interdicted, adding a social character to this level.

b) The SECOND LEVEL occurred at the GOIÂNIA GENERAL HOSPITAL – GGH where a special ward was prepared with contamination control. Immediately the location was divided into a "free area" (no contamination expected), a "supervised area" (a radiation control point) and a "controlled area", were patients were admitted.

During September 30 and the dawn of the next day the three physicians in charge re-evaluated the patients at HGG. Six of them were selected and removed by air on October 1 to MARCILIO DIAS NAVAL HOSPITAL – MDNH in Rio de Janeiro, accompanied by one of the doctors. These patients were elected for removal in virtue of the severity of local lesions, the ARS manifestations and in one case because of probable massive internal contamination, confirmed later[12].

c) As aforementioned, victims with the most severe conditions were referred to MDNH (THIRD LEVEL). Both in GGH and MDNH treatment focused on local injuries (topical creams, use of analgesics and opiates, debridement and surgery at a later stage), on the ARS and different degrees of bone marrow depression (reverse isolation, gut sterilisation, prophylactic and curative antibiotics, blood and derivates transfusions — as platelets concentrates and the use of a bone marrow stimulant factor — GM-CSF[13]) and also on the decorporation of caesium with the use of Prussian Blue[6-7-9-10].

One patient had his right forearm amputated at MDNH in a life saving procedure.

3. CONCLUSIONS

Although not producing a large immediate death toll, the Goiânia misadventure caused a very impressive public impact, in virtue of its social, economical, ambiental and political aspects too.

The accident highlighted the need for well designed plans to respond to mass disasters of any kind. The implementation of a medical response in Goiânia based on a three level system was an important factor in mitigating the consequences of the casualty. This was one of the reasons why the University of the State of Rio de Janeiro and its Laboratory of Radiological Sciences – LSR have recently submitted to the Brazilian Health Ministry a similar medical plan to be triggered in radiation emergencies. This plan has been approved and is to be implemented on a nation-wide basis.

The continuous training of emergency personnel on radiation issues is one of LSR`s goals "Radiophobia" was an important initial mishap in Goiânia and this kind of problem can only be overcome by means of education and training.

Medically, many lessons stemmed from the Goiânia experience14. Amongst them, the unique large use of Prussian Blue and its comprobatory effect in decorporating caesium. Also the first administration of GM–CSF in a radiation accident can be mentioned although its use in a late stage of the bone marrow depression precluded any conclusion of its effectiveness in that occasion.

Finally, it must be stressed how valuable the multi-institutional and international participation was, the latter consisting of medical advising, parallel laboratory testing and the supply of special drugs such as GM–CSF.

REFERENCES

[1] LEWIS, H.W., Technological Risk, First edition, New York, W.W. Norton and Company (1990) 3–11.

[2] DUCALTMAN, A.M., Occupational Physicians and Environmental Medicine, J. Occup. Med., **35** (1993) 251–259.

[3] DELTART, R.Y., Accepting the Environmental Medial Challenge, J. Occup. Med., **35** (1993) 265–266.

[4] KELLY, R.B., Industrial Emergency Preparedness, New York, Van Nostrand Reinhold (1989) 1–9.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA), Bulletin 2 (1987).

[6] The Goiânia Radiation Accident, Health Physics, **60** (1991).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, Vienna (1988).

[8] The Medical Basis for Radiation Accident Preparedness III. The Psychological Perspective, (RICKS, R.C., et al., Eds.), New York, Elsevier (1991).

[9] VALVERDE, N.J., CORDEIRO, J.M., et al., The Acute Radiation Syndrome in the 137-Cs Brazilian accident, 1987, (RICKS, R.C., FRY, S.A., Eds.), The Medical Basis for Radiation Accident Preparedness II, New York, Elsevier (1990) 89–107.

[10] OLIVEIRA, A.R., VALVERDE, N.J., The Goiânia Radiological Accident, (BIGGOT, J.M., MOREAU, J.F., et al., Eds.), Radiology-Proceedings of the 17 th International Congress of Radiology, Paris, 1–8 July 1989, Amsterdam, Elsevier (1990) 135–142.
[11] Facilities and Medical Care for On-Site Nuclear Power Plant Radiological Emergencies, American Nuclear Society, ANSI.

MEDICAL EXPERIENCE: CHERNOBYL AND OTHER ACCIDENTS

XA0054890

D. DENSOW, H. KINDLER, T.M. FLIEDNER
Institut für Arbeits- und Sozialmedizin der Universität Ulm,
Ulm, Germany

Abstract

MEDICAL EXPERIENCE: CHERNOBYL AND OTHER ACCIDENTS.

A radiation accident can be defined as an involuntary relevant exposure of man to ionising radiation or radioactive material. Provided one of the ensuing criteria is met with at least one person involved in an excursion of ionising radiation and or radioactive material, the respective incident can be considered a radiation accident in accordance with ICRP, NCRP (US), and WHO :

- ≥0,25 Sv total body irradiation with lesions of the rapidly dividing tissues;
- ≥6 Sv cutaneous and local irradiation;
- ≥0,4 Sv local irradiation of other organ systems through external sources;
- incorporation equal to or in excess of more than half of the maximum permissible organ burden; and
- medical accidents meeting one of the above criteria.

Several actions have been taken to categorise radiation accidents in order to learn from previous accidents in terms of both managerial and medical experience. For this presentation three approaches will be discussed concerning their relevance to the individual treatment and risk management. This will be obtained by applying three classification schemes to all known radiation accidents:

1. classification with respect to the accident mechanism,
2. classification concerning the radiation injury, and
3. classification concerning the extent of the accident.

In a fourth chapter the efficacy of bone marrow transplantation will briefly be commented on based on the accumulated experience of about 400 radiation accidents world-wide.

2. CLASSIFICATION WITH RESPECT TO THE ACCIDENT MECHANISM

The classification by the accident mechanism is related to the names of C. C. Lushbaugh and S. Fry and others who originally devised that scheme for the Oak Ridge radiation accident registry. The accidents are analysed by physical criteria of their mechanism (Lushbaugh 1981, 1990).

When analysing the data concerning the mechanism, it becomes apparent that firstly there is no increase in the number of radiation accidents any longer. Secondly, the radiography accidents have declined sharply through means of technical improvement of the sources, whereas, the medical radiation accidents have increased. Thirdly, with the exception of Chernobyl criticality accidents have disappeared at all. This is also well in contrast to the statement of Mettler (Mettler 1990a, b) that most fatalities were results of industrial radiation accidents. Instead, the medical misadventures have accounted for most of the fatalities.

3. CLASSIFICATION CONCERNING THE RADIATION INJURY

From a medical viewpoint it is seemingly quite natural to classify accidents by the consecutive injury both concerning the individual and the potential harm to larger parts of the personnel and or residents living close to accident sites (Fliedner 1982, Kirchhoff 1980, Rabin 1986). By the type of related injuries four accident classes can be identified:

Table 1: The Different Accident Mechanisms as Identified in the Oak Ridge Registry and Examples

Accident Mechanism	Example
• Criticality	
critical geometry	Oak Ridge Y-12, 16 06 1958,
reactor accidents	Chernobyl, 26 04.1986,
radiochemical reactions	Los Alamos, 30 12.1958,
• Radiation Devices	
sealed radiation sources	Sor-Van, 3 9 1990, Cottbus, 1983/1984, 61 involved, approx. 30 deaths
x-ray devices	England 1961, 11 involved,
radar generators	Lockport 1960,
accelerators	Yakima, Wa 1987 2 deaths; Hamburg, 1972, 9 involved
• Radioisotopes	
Tritium	Switzerland, 1957
transuranics	Oak Ridge X-10,
radioactive fission products	Eniwetok,
diagnosis and therapy	Houston, Tx 1980, 7 deaths by ^{90}Y
others	Gore, Okl. UF_6 with 110 involved

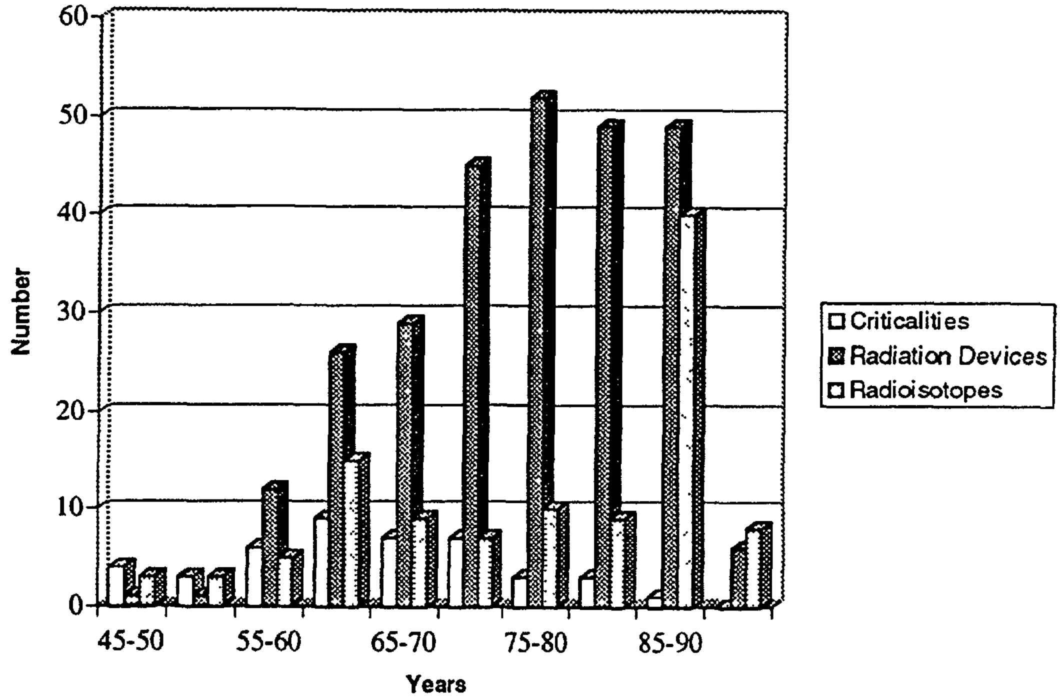


Figure 1: Comparing Radiation Accidents in Terms of Different Mechanisms

- Penetrating total or partial body exposure — the severity is closely related to the deposition of energy, the part of the human body exposed, and the duration of the exposure. Usually, a victim of this type of accident will pose no threat to the public. The managerial problems are solely related to the handling of the acute radiation syndrome [Nesvidge, Belarus, 1991].
- External contamination with radionuclides — again, the severity is closely related to the deposition of energy. However, the effects will be dependent on amount, extent of body surface, duration of exposure, type of radiation emitted (LET, penetration), and the contaminating isotope. Main managerial issues with this type of accident are to

avoid ingestion and absorption on the side of the individual, and in terms of public health aspects to avoid further contamination through the victim(s) of areas beforehand unaffected [Switzerland 1957].

- Internal contamination with radionuclides — the severity is also related to the local energy deposition, but is dependent from the radio sensitivity of the neighbouring tissues and both the chemical and physical properties of the intruding isotopes. With internal contamination especially the aspects of decorporation will be of medical concern. Questions to be addressed are in this case the biological half life and the toxicity of the respective compound. [Houston, Tx. 90Y — accident (Lincoln 1976)].
- Combinations of the above — sometimes even complicated by other traumas, e.g. burn or fractures. Physical trauma will substantially reduce the chance for survival [Chernobyl].

4. CLASSIFICATION CONCERNING THE EXTENT OF THE ACCIDENT

Thirdly, radiation accidents can be classified by their size. This type of categorisation stresses the managerial problem of the handling of mass casualties. Considerations concerning the size of the accident are especially relevant when trying to learn lessons from previous accidents in terms of preventing catastrophes from occurring or at least to have at hand some procedures to follow if a large scale accident happens.

After intense brain storming with Prof. Jammet it has been decided that three categories can be identified concerning the accident size (Densow 1993):

- small accidents, with less than ten persons involved, e.g., radiation devices,
- medium size accidents , with more or equal than 10 up to 100 persons involved, e.g., medical accidents, and
- large scale accidents involving at least 100 people.

Whereas, category 1 in the Federal Republic will require only the emergency system of the workmen's compensation board to become activated, the second level will demand countermeasures at least on the part of the state government, if not the federal government. Coming to the third with hundreds of people involved it is hardly imaginable that the situation can be handled by one individual member of the EU states. It is almost certain that the Commission of the European Union will have to react in order to assist the member country befallen by disaster (BMI 1986).

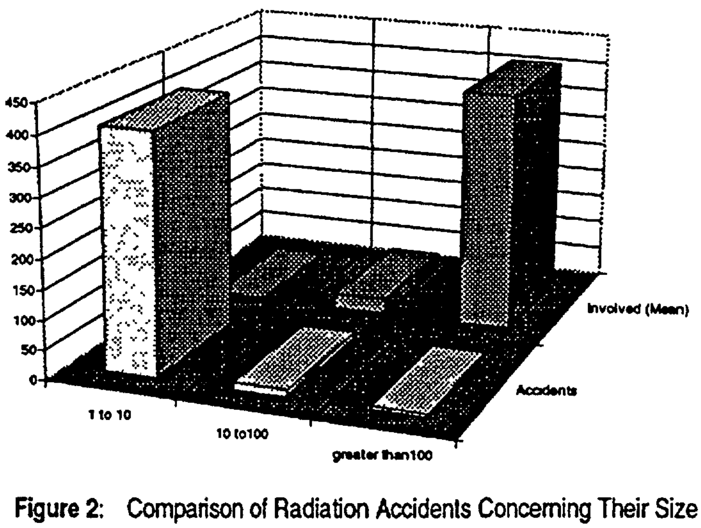


Figure 2: Comparison of Radiation Accidents Concerning Their Size

TABLE II. ACUTE RADIATION SYNDROME (ARS) PATIENTS WITH VERY SEVERE MYELODEPRESSION WITH AND WITHOUT TRANSPLANTATION OF BONE MARROW (BM) OR FETAL LIVER CELLS (FLC) (BARANOV 1993, 1994)

	Code of Case	Irradiation		Transplantation		Death	
		Type	Dose	Day	Type	Day	Cause
1	3091 Mich	γ, n				5	GIS, RB
2	3090 Bor	γ, n				8	GIS, RB
3	3031 Vas	γ, n	20	—		6	GVS, GIS, RB
4	3056 Kor	γ, β				7	RB, GIS
5	3092 Sek	γ, n		—		12	GIS
6	LASL-II N3	γ, n	20	—		9	GIS, RB
7	Wood River Jct 10	γ	10			21	cardiac arrest
8	1023 Pra	γ, β	14	11	FLC	15	RB, GIS
9	1020 OH	γ, β	12	13	FLC	17	RB, GIS
10	3055 Kosh	γ, β				7	RB, GIS
11	3088 Shu	γ	14			113	Infection
12	1015 Tish	γ, β		13	FLC	14	GIS, ARDS, RB
13	Kjeller	γ	20			13	acute heart failure
14	1017 Vats	γ, β	9	16	BM, h, tcd	18	RB, GIS, ARDS
15	1026 Tit	γ, β	13			20	RB, GIS
16	1009 Sha	γ, β	10	12	BM, id	23	RB, GIS, ARDS
17	3032 Ero	γ, n				14	RB, GIS
18	1010 Kib	γ, β	11	9	FLC	14	RB, GIS
19	Sor Van	γ	>10	4	BM, h, tcd	36	aGvHD, viral infection
20	1012 Bar	γ, β	9			24	GIS, ARDS
21	3061 Ord	γ, β				8	RB, GIS
22	Brescia	γ	12			12	CNS lesion
23	3064 Sav	γ, β				9	RB, GIS
24	1003 Ign	γ, β		6	BM, id	17	RB, GIS
25	3063 Har	γ, β				11	RB, GIS
26	1016 Nov	γ, β	10	12	BM, h, tcd	91	aGvHD, CMV infection
27	1014 Bra	γ, β	11	9	FLC	18	RB
28	3057 Pen	γ, β				13	RB, GIS
29	1004 Top	γ, β	11	7	BM, h1	18	RB
30	1002 Aki	γ, β	9	4	BM, id	15	ARDS, RB
31	1008 Iva	γ, β	8	13	FLC	30	RB
32	1027 Per	γ, β	8	13	BM, id/h ?	24	RB, GIS, GvHD?, ARDS
33	1029 Tor	γ, β	9	14	BM, h, tcd		
34	1031 Kon	γ, β	7			32	RB, GIS, ARDS
35	3046 Sap	γ, n					RB
36	1022 Kom	γ, β	7				
37	3017 Alek	γ, n					
38	3047 Milo	γ, n				52	RB
39	Goiânia D	γ	7				
40	1062 Pros	γ, β	6			21	RB
41	3075 Egor	γ	7	26	BM, id	33	systemic fungal infection
42	1028 Pop	γ, β	6	11	BM, id	48	aGvHD, fungal infection
43	1025 Kur	γ, β				16	RB & TB
44	1001 Sav	γ, β	7	6	BM, h1	25	RB
45	Byc Tu 6	γ	6			17	septicaemia, gut lesion
46	1006 Vers	γ, β	5	9	BM, id	86	aGvHD, infection
47	1005 Sit	γ, β	4	7	BM, h1	34	HvGD, ARF,
48	3065 Ber	γ, n					
49	1034 Pere	γ, β	6			48	RB
50	1007 Kud	γ, β	5				allergic shock
51	3009 Sad	γ, n					
52	1071 Kitc	γ, β	5				
53	1011 Pal	γ, β	5	13	BM, h, tcd		
54	Vinca V	γ, n			BM, unmatched	30	pulmonal haemorrhage
55	Pittsburgh C	x-ray	6	9	BM, Sin		
56	Shanghai 80	γ	5	5	FLC		

BM - Bone Marrow; FLC - Fetal Liver Cells; id - HLA identical; h - HLA haploidentical; h1 - HLA haploidentical with one antigen plus on 2nd chromosome 6; tcd - T-cell depletion; causes of death: aGvHD - acute graft versus host disease; ARDS - adult respiratory distress syndrome; ARF - acute renal failure.; CVS - cardiovascular syndrome; GIS - gastrointestinal syndrome; HvG - Host versus Graft; MV - Cytomegalovirus; RB - radiation skin burns; TB - thermal skin burns.

As it becomes evident from Fig. 2 roughly 90% of the radiation accidents however, involve about one individual only, leaving a tiny fraction of less than a percent actually to be considered as a disaster, amongst which Chernobyl and Goiânia are the most prominent examples.

LESSONS LEARNED ON THE TREATMENT OF THE ARS

From lessons learned 25 years ago it has been believed that about 6 Gy TBI will be a lethal dose to man since the stem cells will all be killed and, consequently, BMT will be required. However, the gloomy perspective of those radiation accident victims submitted to BMT, proved that accompanying injuries and disease turned out to be even more effective in terms of lethality than the bone marrow syndrome itself.

The most pressing questions are on the eligibility for BMT, whether an accident will benefit from BMT and by which degree lethality will increase when submitting a patient to a BMT regimen. As depicted in Table II most of the patients with very severe ARS have died despite BMT. The main reasons seem to be that victims of nuclear accidents almost always suffer from accompanying skin burns and trauma of other organs that reduce the probability of survival further. Adding to that is the arduous donor selection. On the one hand, there is difficulty in obtaining sufficient numbers of lymphocytes able to divide in cell culture for HLA typing. More so, mostly only HLA haploidentical donors can be identified, thus, the graft is prone to rejection by mismatch. The higher frequency of infectious complications for reasons of incomplete gnotobiosis and possibly due to transfusions is remarkable if compared to BMT for other reasons. The above stresses the importance of a conditioning regimen prior to BMT even after accidental total body irradiation. Nonetheless, it seems risky though and questionable to submit critically ill people to such aggressive treatment.

In his publication for the 2nd Consensus Building Conference held in Bethesda, MD last year Prof. Baranov stated (Baranov 1993):

1. BMT will never be needed, provided the individual had been exposed to gamma-neutron or gamma-beta accidental overexposure (predominantly due to inhomogeneity and accompanying burns).

BMT however may prove effective in cases of exposure to high dose gamma sources in irradiation facilities, especially when dose estimates are in excess of 10 Gy TBI.

Are there any other alternatives? The usage of haemopoietic growth factors did not show any harmful side effects [Goiânia 1987]. It may turn out however, not to be too effective either, since the example of the Nesvidge, Belarus, patient demonstrated that even though the granulocytes did recover to about 1 Giga/l the platelets did not.

6. CONCLUSION

Especially the perspective laid out in the last paragraph raises the question of what could be done in case of a severe ARS into a rather gloomy perspective. However, it should have become evident that three lessons can be learned from a thorough analysis of radiation accidents:

1. whenever possible accidents should be analysed in terms of optimising the technical equipment to prevent accidents from happening,

2. proper management plans have to be devised in order to be prepared for radiation medical emergencies, and
3. to intensify the research in establishing a proper prognosis of the ARS as early on as possible in order to decide which patients will benefit most from supportive treatment, haemopoietic growth factors, and BMT. The latter should, however, clearly be considered as a weapon of last resort.

REFERENCES

[1] BARANOV, A.E., Is Allogenetic Bone Marrow Transplantation Needed in the Case of Severe Uniform Whole Body Irradiation?, Proceedings of the 2nd Consensus Building Conference Bethesda, MD, (1993).

[2] BARANOV, A.E., DENSOW, D., FLIEDNER, T.M., KINDLER, H., Clinical Pre Computer Proforma for the International Computer Database for Radiation Exposure Case Histories, Springer Verlag, Berlin, Heidelberg (1994).

[3] BUNDESMINISTER DES INNERN (BMI) (ed.), Medizinische Maßnahmen bei Kernkraftwerksunfällen, Veröffentlichungen der Strahlenschutzkommission, Vol. 4, Gustav Fischer Verlag, Stuttgart, New York (1986).

[4] DENSOW, D., FLIEDNER, T.M., ARNDT, D., Übersicht und Kategorisierung von Strahlenunfällen und -katastrophen als Grundlage medizinischer Maßnahmen, Veröffentlichungen der Strahlenschutzkommission, Gustav Fischer Verlag, Stuttgart, New York, to appear (1993).

[5] LUSHBAUGH, C.C., FRY, S.A., HÜBNER, K.F., RICKS, R.C., Total-body Irradiation: A Historical Review and Follow-up, (HÜBNER, K.F., FRY, S.A., Eds.), The Medical Basis for Radiation Accident Preparedness, Elsevier/North-Holland, New York (1980).

[6] LUSHBAUGH, C.C., FRY, S.A., ORISE-Database on Radiation Accidents, private communications (1991).

[7] KIRCHHOFF, R., LINDE, H.J. (Eds.), Reaktorunfälle und nukleare Katastrophen, Notfallmedizin, Vol. 1, Perimed Verlag, Erlangen (1980).

[8] LINCOLN, T.A., Importance of initial management of persons internally contaminated with radionuclides, Am-Ind-Hyg-Assoc-J, **37** 1 January 1976 16–21.

[9] METTLER, F.A., KELSEY, C., Fundamentals of Radiation Accidents, METTLER, F.A, KELSEY, C A, RICKS, R C, Medical Management of Radiation Accidents, CRC Press, Boca Raton, Fla. (1990).

[10] METTLER, F.A., RICKS, R.C., Historical Aspects of Radiation Accidents METTLER, F.A., KELSEY, C.A., RICKS, R.C.,: Medical Management of Radiation Accidents, CRC Press, Boca Raton, Fla. (1990).

[11] RABIN, S.M., Medical Intervention in a Nuclear Accident, Hospital Practice, November 15 (1986) 137–52.

POST-TRAUMATIC STRESS DISORDERS: AFTEREFFECTS OF THE GOIÂNIA RADIOLOGICAL ACCIDENT

A. BANDEIRA DE CARVALHO
Comissao Nacional de Energia Nuclear,
Rio de Janeiro, Brazil

Abstract

POST-TRAUMATIC STRESS DISORDERS: AFTEREFFECTS OF THE GOIÂNIA RADIOLOGICAL ACCIDENT.

In September of 1987, a ^{137}Cs medical source was violated in the city of Goiânia, Brazil and, as a result, four people died, 249 were internally and/or externally contaminated and 20 people were hospitalised at the Goiânia General Hospital. The most serious cases were transferred to the Marcílio Dias Naval Hospital in Rio de Janeiro.

The objective of this paper is to describe the emotional and social impacts caused by this accident on the hospitalised victims.

As these people belonged to a low social-economic level and did not understand the meaning of radioactivity, panic only started to be felt with the first deaths. The origin of their stress was, primarily, the radiation syndrome, but mostly the rejection suffered by them in the Goiânia General Hospital, caused by fear of radioactivity; the difficulty in understanding the safety regulations; the always covered staffs; and the isolation due to immune-suppression. They feared having a limb amputated, were worried about their families, ambivalent about death: wishing and afraid of it. They felt guilty about the accident but at the same time they were seeking compensation from the State. Aggressive, due to the long confinement, they rioted inside the hospital. The need for psychological support was felt by the staff but few psychologists volunteered because of fear.

Human beings present a number of psychological disorders after the trauma suffered in a catastrophe. These have a pattern, called post-traumatic stress disorders, which was noticed in this accident. It is a lesson learned in Goiânia that psychological support is of vital importance to help the patient fight the consequences of the suffering. Psychologists should be trained to work without fear, during emergencies of this kind.

1. INTRODUCTION

On September 13, 1987, a shielded ^{137}Cs source (50.9 Tbq; 1375 Ci) was stolen from the abandoned and partly demolished Goiânia Radiotherapy Institute in Goiânia, Brazil, by two scavengers and sold to a junkyard. A child, a woman and two men died as a consequence of the accident, 249 people were internally or externally contaminated; 20 were hospitalised and 30 remained under medical observation at a primary-care unit and two hostels. 28 patients suffered radiation burns.

The objective of this paper is to describe the psychological effects caused by this accident and describe behavioural disturbances and social consequences during the time of hospitalisation.

2. POST-TRAUMATIC AFTER EFFECTS

The people who were hospitalised belonged to a low social level, the majority of them were junkmen, or members of their family, and at first were not concerned with the consequences of the accident or aware of the risks involved.

Twenty people were admitted to the Goiânia General Hospital, **HGG**, a government hospital which at that time was on strike with only its emergency section functioning. The

HGG's director had arranged the evacuation of one ward to receive the victims and here they were left without attention, either because of fear or lack of preparation from the hospital staff regarding radiation syndrome. Their treatment only began in the evening of September 30, when physicians from Rio de Janeiro arrived and found the patients sitting together very near each other, left to themselves, feeling pain and fear. Among them were two children. They remained in the hospital until January, 1988 and as time passed, the confinement became more irritating and stress increased. Behavioural disturbances started to appear and in some cases of a severe nature. Without their past histories, comparisons could not be made, but the fact is that before the accident these people were leading what was considered normal lives, within their social contexts. Some of them tried to run away, others broke everything in sight and were very aggressive with the staff. A psychiatrist was called, and at the end of October psychologists were asked to give them psychological support. Very few volunteered because they were much afraid of radioactivity and it was difficult for them to help.

The victims were aware of the ostracism within the hospital. They were famous and at the same time discriminated and afraid of. The doctors and nurses were totally covered by masks and protective overalls, preventing them from human contact. According to the staff, the segregation and the need to see the faces of the people who treated them caused great anguish.

On October 1, the physicians decided to transfer to the Marcílio Dias Naval Hospital, **HNMD,** Rio de Janeiro, six of the most injured victims. On October 3, four more were transferred and then other four between October 19 and 31. All patients felt negative impact when one of their number was transferred to Rio de Janeiro, or when there was news of a death, their morale deteriorated and they experienced severe depression.

The staff in attendance at **HNMD** stated that at first, when the symptoms were still not intense, they were impatient with all the protective apparatus and procedures. The real fear started with the first deaths, that the next might be their own, and even those with less contact with reality ran the gamut of suffering, emotional, social and primarily physically. They remained isolated from their families and the women patients longed for their children: visits were forbidden.

They were viewed as objects of scientific curiosity and were frequently photographed or examined by doctors who did not belong to the **HNMD**'s team. These visits from the merely curious scientific community, who had no connection with the hospital work groups, made them feel like guinea pigs, humiliated, hurt. Anyone with an infection or the suspicion of one, was isolated and as two patients died in isolation, fear of being isolated generated enormous tension. All had serious lesions on feet and hands and at any thought of amputation they stopped eating and sleeping, or if they slept they were subjected to nightmares, their aggressive behaviour increased and they refused medication.

A member of the staff at **HNMD** relates that innumerable manifestations of negation, anger and depression appeared among the most severely affected patients, along with an intense desire to die and be rid of the suffering. There was also much discussion among the victims as to who was to blame for the accident, and there was accusations and quarrels. **TV** announcements of the deaths were seen by the victims in the hospital and the articles written on newspapers and magazines about how caesium may cause cancer created much distress and depression among them. But they faced facts in a fatalistic manner, believing that if someone died it was because he was meant to die, and if they suffered, it was because they deserved it. At the same time they never stopped thinking of the secondary advantages of the accident, such as compensation from the State for the loss of their possessions, wanting to receive even more than what they actually had owned.

3. RECOMMENDATIONS AFTER LESSONS LEARNED AND CONCLUSION

Human beings present a number of psychological disorders after a catastrophe. These depend on how the person is able to cope with the stress for coping styles are important moderators of life stress-psychopathology relationship or behaviours in response to a specific event. A traumatic neurosis may develop after the occurrence of an unexpected event of great emotional impact. The psychic system tries to maintain itself in balance but the Ego, part of the system, looses it's strength. Some of the symptoms are:

- blocking or diminishing the Ego's diverse functions, such as motility control, contact with reality, etc.;
- excess of uncontrolled emotion, especially anxiety and frequently rage;
- insomnia, or serious perturbation during sleep, such as nightmares or dreams in which the trauma is released; and
- secondary psychoneurotic complications such as the liberation of nuclei of pre-existent mental illness.

The consequences of the overwhelming stress caused by hospitalisation due to contact with radioactive material may produce symptoms of a traumatic neurosis. As the victim arrives for treatment, it is necessary to know exactly how he perceives the risks, what are his knowledge about radioactivities, his attitudes and beliefs. Upon being informed of his condition, the victim may be profoundly shocked and the immediate help of a hospital psychologist is important. The patient should be made to understand that they are fighting together in the process of his own cure, and a positive response to this challenge is beneficial as a form of Ego strengthening.

There is a great deal of involvement with the hospital staff, as well as with the radioprotection team, who are called upon to give emotional support and encouragement. The patients become very exigent in their fear and pain and highly dependent on this group that should understand clearly this additional role which they must undertake.

An aggravating factor to the emotional state of the patient is the total lack of physical contact with other people. The division of the infirmary into "hot", "warm" and "cold" areas and the eternal presence of radiation monitors and radioprotection procedures, all intensify the stress. Everything should be clearly explained to the patient about the "why", because in understanding the security procedures, these will be better accepted by him.

Secondary benefits play a major role in the treatment. The demonstration of his infirmity and the need for compensation must not be put aside, it most be worked through for it is symbolic.

Techniques of hospital psychology may be utilised, such as encouraging the patient to talk about his emotions and to feel that the psychologist understands him. Verbalisation can sometimes neutralise the excessively excited state of the patient, bonding the emotion with the external cause. Behaviour psychology and relaxation techniques are also useful, and when the despair of the patient becomes so great that suicidal tendencies appear, psychiatric intervention may be needed.

If the syndrome progresses rapidly toward death, the person confronts all the sentiments inherent in his state, i.e., negation, fear, hate, depression, ambivalence and search for a meaning to existence. Usually, hospitals have a chaplain and at such a moment, depending of the patient, his intervention can be very beneficial and soothing.

Group dynamics can be helpful when there are many victims. It diminishes the tension during hospitalisation for there is an exchange among the patients about their fears and feelings. Concern about their bodies, the fear of mutilation and of amputation should be worked through. If the patient looses a limb, there must be work done toward acceptance of this fact and later, toward readaptation to the body image.

Symptoms of reactive depression are common during hospitalisation. In this case, it is possible that a subtype called hopelessness depression may develop due to attributions given negative life events, attachment of high importance to event and inferred negative characteristics about self. Prevention efforts could be aimed at building nondepressive cognition styles and the focus of therapy would be on the context of the person's inferences and beliefs. The feeling of aimlessness should be avoided, a search for a meaning in life could be achieved after discharge.

The social worker can be of help in the hospital, part of the mental health team, finding out how these people can be assisted during the treatment and how they are reacting to the accident, control the information of an alarming nature, control letters sent and received, and install a special telephone line for communication with the families. It was seen in Goiânia how the women patients were worried about their children.

The mental health team should have a voice in the clinical treatment, so that decisions might be weighed jointly as to when medical intervention might be more prejudicial than beneficial for the body-mind system of the patient. The team could also control the visits of curious professionals, with their cameras and films, which leave the patients with a feeling of being objects of scientific curiosity.

It is a lesson learned in Goiânia that mental health teams should be trained to deal with future emergency situations, prepared to enter into immediate action, instead of having to delay until their entirely normal fears are overcome. Training should cover some knowledge about public acceptance of nuclear energy; some knowledge of radiation medicine, basic knowledge of radioprotection, practical training with simulation wearing protection clothes. This team should be composed of a hospital psychologist, a psychiatrist, psychologists with special training in behaviour therapy, in group dynamics and in family therapy, a social worker and a hospital chaplain. And finally, a specialisation in psychology, clearly designated in this area of practice, using a new theory, should be created to help the victims of radiation accidents.

REFERENCES

[1] ANON, Radiation sources: lessons from Goiânia, International Atomic Energy Bulletin **30** 4 Vienna (1988)10–16.

[2] BRANDÃO-MELLO, C.E., OLIVEIRA, A.R., CARVALHO, A.B., The Psychological effects of the Goiânia radiation accident on hospitalised victims, (RICKS, R.C., BERGER, M.E., O'HARA, F.M., Eds.) The Medical Basis for Radiation Accident Preparedness III, Psychological Perspectives, Elsevier Science Publishing, New York (1991).

[3] CARVALHO, A.M., psychiatrist, Goiânia, personal communication, April (1988).

[4] MONTEIRO, P., veterinary physician, (received the source from one of the victims), personal communication, March (1988).

[5] PINTO, L.G., psychologist form HGG, (gave the victims psychological support), personal communication, March (1988).

[6] OLIVEIRA, A.R., et al., Medical and related aspects of the Goiânia Accident: an overview, Health Physics **60** 1 (1991) 17–24.

[7] ROCHA, S., chief-nurse from HNMD, personal communication, April (1988).

[8] MUGNOL, O., chaplain-psychologist from HNMD, personal communication, April (1988).

[9] CARVALHO, A.B., The psychological impact of the radiological accident in Goiânia, Recovery Operations in the Event of a Nuclear Accident or Radiological Emergency. IAEA-SM-316. International Atomic Energy Agency, Vienna (1989).
[10] AMARAL, R., psychiatrist, Goiânia, (treated the victims at HGG in October, November, and December, 1987), personal communication, March (1988).
[11] FENICHEL, O., The Psychoanalytic Theory of Neurosis, transl. Carlisky, Teoria Psicanalitica de las Neurosis, Editorial Paiados (1973) 141–145, 151–152, 282, 292.
[12] CARVALHO, A.B., The Psychological effects of the Goiânia radiation accident on the emergency responders, (RICKS, R.C., BERGER, M.E., O'HARA, F.M., Eds.) The Medical Basis for Radiation Accident Preparedness III, Psychological Perspectives, Elsevier Science Publishing, New York (1991) 131–141.
[13] ABRANSON, L., METALSKY, G., ALLOY, L., Hopelessness depression: a theory-based subtype of depression, Psychological Review, American Psychological Association, Vol. 96, No. 2, April (1989).
[14] BLAZER, J., The Relationship between meaning in life and fear of death, Psychology, Part 10, (1973) 33–34.
[15] GIST, R., Role of the mental health professional in minimising the psychological consequences of radiation incidents, (RICKS, R.C., BERGER, M.E., O'HARA, F.M., Eds.) The Medical Basis for Radiation Accident Preparedness III, Psychological Perspectives, Elsevier Science Publishing, New York (1991).

RETROSPECTIVE EPR DOSIMETRY ON THE BASIS OF TOOTH ENAMEL ANALYSES OF TECHA RIVER AREA RESIDENTS

XA0054892

A. WIESER
GSF—Forschungszentrum für Umwelt und Gesundheit,
Neuherberg, Germany

A.A. ROMANYUKHA
Russian Academy of Science,
Institute of Metal Physics, EPR Spectroscopy Centre,
Ekaterinburg, Russian Federation

V.P. KOZHEUROV, M.O. DEGTEVA
Urals Research Centre for Radiation Medicine,
Cheljabinsk, Russian Federation

Abstract

RETROSPECTIVE EPR DOSIMETRY ON THE BASIS OF TOOTH ENAMEL ANALYSES OF TECHA RIVER RESIDENTS.

The dose in tooth enamel from residents of villages along the Techa river was measured by EPR dosimetry. The results were correlated to the ^{90}Sr whole body burden as measured about 30 years after ingestion. Based on the results of this preliminary investigation the ingestion dose coefficient of tooth enamel for ^{90}Sr is estimated and compared with the value for bone surface given in ICRP. The results of the preliminary study suppose a similar metabolism of strontium for tooth dentine and the skeleton.

1. INTRODUCTION

In the period from 1949-1956 the plutonium production facility MAJAK released 10^{17} Bq of fission products in liquid waste into the Techa river, Southern Ural, Russia. The most massive releases of about 95% of the total activity were in the years 1950 and 1951 (Trapeznikov et al., 1993). About 25% of the released activity resulted from the radionuclides ^{137}Cs and ^{90}Sr. The population of the Techa riverside villages were mainly exposed external by γ-radiation from ^{137}Cs and internal by incorporation ^{90}Sr. The external exposure of the population is decreasing with the increasing distance of the villages from the site of activity release. In a distance further than about 80 km the mean cumulative dose due to external radiation is calculated to be less than 0.1 Gy for all age groups of the population (Degteva et al., 1994). The residents of these villages have been exposed predominantly due to the ingestion of ^{90}Sr which occurred in the period 1950–1959. The main pathways of ingestion were drinking water, milk and fish. The rate of ingestion of the population of the villages along the Techa river varies by about a factor of 10 depending on the habits of life and diet (Kozheurov and Degteva, 1994). In a distance further than about 80 km from the site of activity release the average dose accumulated within 25 years in the bone surface of the residents was calculated to be less than 14 Gy (Degteva et al., 1994). The calculations are based on whole body counter measurements (Kozheurov, 1994) and a model for strontium retention by Degteva and Kozheurov (1994).

At present, electron paramagnetic resonance (EPR) dosimetry using teeth is the only *solid state dosimetry method which allows for retrospective dose assessment at the individual.* EPR dosimetry using tooth enamel was done for dose evaluation for atomic bomb survivors (Ikeya et al., 1984) and nuclear workers (Romanyukha et al., 1994). The method makes use of

(Ikeya et al., 1984) and nuclear workers (Romanyukha et al., 1994). The method makes use of the formation of stable radicals proportional to the absorbed dose in hydroxyapatite, the mineral component of tooth enamel, dentine and bone (Cevc et al., 1972; Moens et al., 1993). At 25°C a lifetime of 10^7 years (Schwarcz, 1985) was determined for the radicals. Therefore EPR dosimetry of tooth enamel seems to be suitable for individual dosimetry after long periods of exposure and for a long time after the exposure. However, the dose reconstruction for the population of the Techa riverside villages is complicated due to the combined contribution of external and internal radiation. Further complications result from the different metabolism of strontium in tooth enamel, dentine and bone (Kozheurov and Degteva, 1994). We suggest to measure in addition to tooth enamel the dose in dentine. The complementary measurements of the two tooth components might provide information about the prorated contribution from different radiation sources. The use of tooth dentine for EPR dosimetry in the required dose range so far was not possible due to its high content of organic components. Now, it has become applicable after a method of preparation was developed to remove the organic components by chemical degradation and extraction (Wieser et al., 1994).

In the present pilot study samples of tooth enamel from residents of villages along the Techa river were measured by EPR dosimetry. The samples under investigation were from residents of villages with low external radiation. All persons were older than 6 years at the beginning of the Strontium ingestion and therefore, no or only little strontium is expected inside their tooth enamel (Kozheurov and Degteva, 1994). The cumulative doses in tooth enamel estimated by EPR dosimetry will be related to whole body counter measurements of the tooth donors.

2. MATERIAL AND METHODS

In this preliminary examination from five tooth donors six samples of tooth enamel and one sample of tooth dentine were measured by EPR dosimetry. The teeth were extracted at most two years before the measurement. Some information about the samples and its donors are given in Table I. Details about the β count rate and whole body counter measurements are given elsewhere (Kozheurov, 1994).

The tooth enamel samples were separated from dentine by a dental drill after treatment with sodium hydroxide in an ultrasonic bath (Romanyukha et al., 1994). The tooth dentine sample was prepared from the root of the tooth after treatment with diethyltriamine in an Soxhlet apparatus (Wieser et al., 1994). All samples were ground in a mortar to powder with grain size less than 1 mm. The mass of the individual samples used for measurement varied between 50-150 mg.

The EPR measurements (ESP300, Bruker) were made using a standard rectangular cavity. The spectra were recorded with 5 mT magnetic field sweep, 0.3 mT modulation amplitude, 42 sec sweep time and 82 msec time constant. For each measurement the spectrum was accumulated 40 times. The tooth enamel samples were measured twice with a microwave power of 2 mW and 12.5 mW to apply the selective saturation method for reduction of the background EPR signal (Ignatiev et al., 1994). The tooth dentine sample was measured with a microwave power of 12.5 mW. Due to the strong EPR signal from hydroxyapatite in the dentine sample a reduction of the background was not necessary.

The dose reconstruction was done by the additive dose method with an unweighted linear least-square-fit. Six measurements, one original and five after additional irradiation were used for dose reconstruction of the samples. The precision of the individual measurement of the amplitude of the $g_\perp = 2.0018$ EPR signal from hydroxyapatite was 10% and 20% for tooth dentine and tooth enamel, respectively. The irradiations were made within an accuracy of ±3% with ^{60}Co source (Eldorado) with a dose rate of 0.1 Gy/min. The calibration of the source was converted to absorbed dose to tooth enamel (Hubbell, 1982).

3. RESULTS AND DISCUSSION

The results of the investigation are summarised in Table I. The γ-dose resulted external due to the contamination of the Techa river and internal due to incorporation of ^{137}Cs. It was calculated to be 50±10 mGy for all samples. Within the limits of error no β-activity was measured in the tooth enamel of the residents which were older than 10 years at the beginning of the strontium ingestion. A weak activity was detected in the tooth enamel (sample r2) from the resident which was 6 years old at the inset of ingestion. About 30 years after the end of strontium ingestion whole body counter measurements were made in 1992-1993. At this time, the measured whole body burden was in the range of 1–8 kBq for all residents under investigation. The dose in tooth enamel was estimated by EPR dosimetry. Hereby, the variable thickness of the layer of enamel for different teeth is not considered. In average the thickness of enamel layers for all teeth was found to be about 0.5±0.2 mm. Especially for the β-dosimetry of ^{90}Sr the ignorance of the thickness of layer will introduce an additional error, but is expected to be less than about 20%. The dose estimated in enamel with a different thickness from a canine (sample r5) and a molar (sample r3) from the same resident agreed within the limits of error of measurement. In the case of one resident (sample r2) the dose was estimated both, in tooth enamel and dentine. The dose in dentine was found to be about 5-fold bigger than in enamel. A big difference is expected between the dose absorbed in the two tooth components if dentine is much stronger contaminated with ^{90}Sr than enamel. The tooth enamel would act predominantly as a β-dosimeter measuring the radiation from the contaminated dentine.

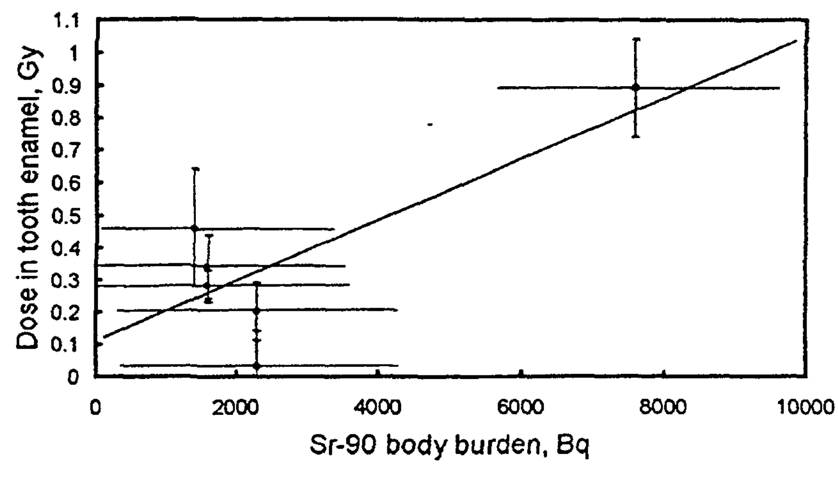


Figure 1: Absorbed dose in tooth enamel versus ^{90}Sr body burden 33 years after end of ingestion.

The absorbed dose in tooth enamel was found to be proportional to the ^{90}Sr body burden for the Techa river residents under investigation (Figure 1). The body burden was measured 33 years after the period of main ingestion of ^{90}Sr. The least square fit of the data (solid line in Figure 1) delivers an intercept with the dose axis, $D_O = 0.1 \pm 0.1$ Gy and a body

Table 1: Sample description and estimated dose in tooth enamel

sample no.; tooth position[1)]	year of birth; settlement; distance from site of release, km	calculated γ-dose, mGy	β count rate of teeth, min^{-1}	^{90}Sr body burden, kBq; year of measurement	EPR dose in tooth enamel, mGy
r2; 6l	1944; Karpino; 96	60	19±3	7.6±2; 1993	890±150 (4300±300)[3]
r7; 5u	1930; R. Techa; 138	60	4±3	2.3±2; 1993	30±110
r3[2)]; 7u	1939; Pershino; 212	50	0	1.6±2; 1992	280±50
r5[2)]; 4l	1939; Pershino; 212	50	0	1.6±2; 1992	340±100
r4; 7u	1939; Klyuchi; 223	40	2	2.3±2; 1992	200±90
r1; 1u	1936; Zatecha; 237	50	0	1.4±2; 1992	460±180

1) l = lower jaw, u = upper jaw.
2) sample no. r3 and r5 are from the same person.
3) EPR dose in tooth dentine.

Table 2: Estimate of ingestion dose coefficient for tooth enamel

measured equivalent dose in tooth enamel per ^{90}Sr body burden, Sv/Bq (30 years after ingestion)	$9.6 \pm 3.9 * 10^{-5}$
retention of ^{90}Sr in skeleton 33 years after ingestion (adults)[1)]	$3.6 * 10^{-3}$
estimated equivalent dose in tooth enamel per ^{90}Sr ingestion[2)], Sv/Bq	$3.5 \pm 1.4 * 10^{-7}$
equivalent dose in bone surface per ^{90}Sr ingestion (adults)[3)], Sv/Bq	$4.1 * 10^{-7}$

1) calculated with model parameters from ICRP Publ. 56/2 including radioactive decay of ^{90}Sr.
2) a single ingestion is assumed for the estimation
3) ICRP Publ. 69

b

burden dose coefficient of 9.6±3.9 * 10^{-5} Gy/Bq (33 years after ingestion). The value of D_O is consistent with the expected external γ-dose.

The experimentally determined body burden dose coefficient for tooth enamel was used to do a first approximation to calculate also the ingestion dose coefficient of tooth enamel (Table II). The approximation assumes a single ^{90}Sr ingestion 33 years before the measurement of the body burden. The fraction of ^{90}Sr retained in the skeleton after 33 years was calculated to 3.6 * 10^{-3} by using model parameters from ICRP Publ. 56/2 and including the radioactive decay of ^{90}Sr. From this the equivalent dose in tooth enamel per ^{90}Sr ingestion is estimated to 3.5±1.4 * 10^{-7} Sv/Bq. The value was found to be very close to the ingestion dose coefficient of the bone surface (4.1 * 10^{-7} Sv/Bq) given in ICRP Publ. 69. This result may suppose that the metabolism of strontium is very similar for tooth dentine and the skeleton.

4. CONCLUSION

In this preliminary examination only teeth were investigated with no ^{90}Sr contamination of the enamel from persons who have received only low external radiation. For this cohort the dose in tooth enamel estimated by EPR dosimetry was found to increase linearly with the whole body burden of ^{90}Sr as measured about 30 years after ingestion. Based on the experimental data of this investigation a first approximation of the ingestion dose coefficient of tooth enamel was found to be very close to the value from the bone surface given in ICRP Publ. 69. It is supposed from the results that the metabolism of strontium for the skeleton and tooth dentine is very similar to each other. The tooth enamel is supposed to measure only the dose resulting from the contamination of the dentine in the case of low external radiation fields and no contamination of the enamel. The dose absorbed in tooth dentine was found to be bigger than in enamel. The ratio of absorbed dose measured in tooth enamel and dentine may provide information to identify the location of the radiation source. Theoretical considerations will be made for predicting the dose ratio dependent on the source location.

ACKNOWLEDGEMENT

We would like to thank Dr. P. Roth (GSF–Institut für Strahlenschutz) for helpful discussions and calculating the retention of strontium in skeletons.

REFERENCES

[1] CEVC, P., SCHARA, M., RAVNIK, C., Electron paramagnetic resonance study of irradiated tooth enamel, Radiat. Research **51** (1992) 581–589.

[2] DEGTEVA, M.O., KOZHEUROV, V.P., Age-dependent model for strontium retention in human bone, Radiat. Prot. Dosim. **53** (1994) 229–233.

[3] DEGTEVA, M.O., KOZHEUROV, V.P., VOROBIOVA, M.I., General approach to dose reconstruction in the population exposed as a result of the release of radioactive wastes into the Techa river, Sci. Total Environ. **142** (1994) 49–61.

[4] HUBBELL, J.H., Photon mass attenuation and energy-absorption coefficients from 1 keV to 20 MeV, Appl. Radiat. Isot. **33** (1982) 1269–1290.

[5] ICRP, Publication 56/2, Age-dependent doses to members of the public from intakes of radionuclides; Part 2: Ingestion dose coefficients, ICRP Publication 67, Annals of the ICRP **23** 3, 4 (1993).

[6] ICRP, Publication 69, (1994), Age-dependent doses to members of the public from intakes of radionuclides; Part 3: Ingestion dose coefficients, ICRP Publication 69 (Publication in 1995).

[7] IGNATIEV, E.A., ROMANYUKHA, A.A., KOSHTA, A.A., WIESER, A., Selective saturation method for EPR dosimetry with tooth enamel, (in preparation) (1994).

[8] IKEYA, M., MIYAJIMA, J., OKAJIMA, S., ESR dosimetry for atomic bomb survivors using shell buttons and tooth enamel, Jpn. J. Appl. Phys. **23** (1984) 697–699.

[9] KOZHEUROV, V.P., SICH–9.1 — Unique whole-body counting system for measuring Sr-90 via bremsstrahlung. The main results from a long-term investigation of the Techa river population, Sci. Total Environ. **142** (1994) 37–48.

[10] KOZHEUROV, V.P., DEGTEVA, M.O., Dietary intake evaluation and dosimetric modelling for the Techa river residents based on in vivo measurements of strontium-90 in teeth and skeleton, Sci. Total Environ. **142** (1994) 63–72.

[11] MOENS, P.D.W., CALLENS, F.J., VERBEECK, R.M.H., NAESSENS, D.E., An EPR spectrum decomposition study of precipitated carbonated appetites (NCAP) dried at 25°C: Adsorption of molecules from atmosphere on the appetite powders, Appl. Radiat. Isot. **44** (1993) 279–285.

[12] ROMANYUKHA, A.A., REGULLA, D., VASILENKO, E., WIESER, A., South Ural nuclear workers: Comparison of individual doses from retrospective EPR dosimetry and operational personal monitoring, Appl. Radiat. Isot. (in press) (1994).

[13] SCHWARCZ, H.P., ESR studies of tooth enamel, Nucl. Tracks **10** (1985) 865–867.

[14] TRAPEZNIKOV, A.V., POZOLOTINA, V.N., CHEBOTINA, M.YA., CHUKANOV, V.N., TRAPEZNIKOVA, V.N., KULIKOV, N.V., NIELSEN, S.P., AARKROG, A., Radioactive contamination of the Techa river, the Urals, Health Phys. **65** (1993) 481–488.

[15] WIESER, A., HASKELL, E., KENNER, G., BRUENGER, F., EPR dosimetry of bone gains accuracy by isolation of calcified tissue, Appl. Radiat. Isot. **45** (1994) 525–526.

XA0054893

RETROSPECTIVE RADIATION DOSE RECONSTRUCTION USING OPTICALLY STIMULATED LUMINESCENCE ON NATURAL MATERIALS

L. BØTTER-JENSEN
Risø National Laboratory,
Roskilde, Denmark

Abstract

RETROSPECTIVE RADIATION DOSE RECONSTRUCTION USING OPTICALLY STIMULATED LUMINESCENCE ON NATURAL MATERIALS.

Optically stimulated luminescence (OSL) techniques especially aimed at using natural materials for retrospective reconstruction of accidental radiation doses in populated areas were developed and studied at Risø as part of an EU research project. Quartz and feldspars separated from building materials, such as bricks and tiles, in addition to porcelain from toilet tanks had their OSL signals measured using different light sources for stimulation to assess radiation doses received by the material. Radiation doses were also evaluated from OSL measured directly on unseparated samples i.e. directly from the surface of brick and tile materials. The lower detection level for e.g. quartz extracted from a modern brick measured using a green light wavelength band as the stimulation light source was found to be less than 1 mGy. The techniques developed and applied are described and results from measurements carried out on a variety of materials are presented.

1. INTRODUCTION

Optically stimulated luminescence (OSL) arises from recombination of charge which has been transferred into metastable locations in the lattice of materials as a result of irradiation, and thus is related to the radiation dose which the materials have received. During the exposure to the stimulation light the OSL signal decreases down to a low level.

Application of OSL for dating of sediments was first demonstrated by Huntley et al. (1985) who used the green light from an argon laser (514.5 nm) to stimulate luminescence from quartz. Luminescence emitted during recombination of the detrapped charges is measured in a spectral region different from that of the exciting photons and is proportional to the radiation dose absorbed in the material. The physical principles of this technique are closely related to those associated with the well known thermoluminescence (TL) technique where heating is used for excitation. However, using light instead of heat to induce recombination clearly simplifies the instrumentation, since there is no need for accurate thermal controls.

The instrumental simplicity of optical stimulation also makes this technique attractive for radiation dosimetry using natural materials collected in the environment. Retrospective dose reconstruction after radiation accidents can be accomplished on the basis of environmental materials which were exposed to radiation during the accident and possess the ability of producing recombination luminescence. Natural dosimeters meeting this requirement are quartz and feldspar inclusions found in fired materials such as bricks, tiles and porcelain where the firing has erased any previously absorbed dose. The cumulative dose accrued from natural sources as well as the accidental dose can be measured either by thermoluminescence (Bailiff and Haskell 1984, Haskell 1993, Stoneham 1985) or by optically stimulated luminescence (Godfrey-Smith and Haskell 1994).

In an effort to apply optical stimulation for retrospective radiation dosimetry a number of basic studies of OSL techniques were undertaken at Risø. The materials investigated include quartz and feldspars extracted from bricks, outdoor tiles and porcelain from toilet tanks.

2. APPARATUS AND TECHNIQUES

The apparatuses used for the experimental work were mainly OSL units developed as attachments to the automated Risø TL reader (Bøtter-Jensen 1987) and include a scanning monochromator for wavelength resolved luminescence measurements. An instrument for continuous OSL scanning of sediment cores was also developed. The latter technique naturally lends itself to the continuous scanning measurements of brick cross-sections, allowing radiation depth dose profiles to be measured directly.

The basic OSL unit, containing light sources for both green light and infrared stimulation, enables measurements of OSL signals from both quartz and feldspar samples (Bøtter-Jensen and Duller 1992). Green light stimulated luminescence (GLSL) is achieved by illumination with a filtered light spectrum from a halogen lamp using exchangeable excitation and detection filter packs. The GLSL unit is designed to select a green light stimulation wavelength band using excitation filters extending to as low a wavelength as possible while still being sufficiently separated from the luminescence emission spectrum. The infrared stimulated luminescence (IRSL) is generated by an infrared diode array (peak emission of 875 ∈ 80 nm) placed close to the sample. While GLSL can be used with both quartz and feldspars, IRSL seems only to work with feldspars.

Ideally, however, the spectral excitation and emission characteristics of quartz and feldspar materials prepared for dosimetric evaluation would be routinely scanned since this would also allow the possibility of choosing the most suitable energy windows in which to carry out the measurements. A compact module was developed that allows for the monochromatic illumination of samples in the wavelength range 380 to 1020 nm, enabling the measurement of energy resolved OSL (Bøtter-Jensen et al 1994). The unit can be directly coupled to the existing automated Risø TL/OSL system. The unit can also be used for recording wavelength resolved emission spectra, whether photo excited or thermally stimulated. A schematic diagram of the combined OSL attachment is shown in Fig. 1.

The continuous OSL core scanner system allows the optical sensors to be moved across either sediment or brick cores. A stepper motor drive ensures constant scan rates and accuracy in positioning to better than 0.1 mm. The optical sensor system was developed at Risp and consists of a photo-excitation and detector module together with lamps for bleaching and regenerating OSL. Photo excitation is made using a filtered halogen lamp generating a green wavelength band (420–550 nm) and the brick core is scanned using an excitation slit beam of 10 mm x 1 mm which determines the resolution of the system. Photo detection is made through a 6 mm standard Hoya U–340 filter (peak emission at 340 nm). OSL dose normalisation is made either by using short wave UV light from a 20 W low pressure HG lamp or exposing the brick cores to a Cs-137 gamma field and afterwards scanning the OSL sensitivity across the brick profile. A schematic diagram of the OSL scanner system is shown in Fig. 2.

3. RESULTS

OSL sensitivity of quartz depends very much on the thermal history of the material: fired samples giving up to an order of magnitude larger signals than non-heated samples. An attempt to determine the lower detection levels using green light stimulated luminescence on fired quartz was made by obtaining dose versus GLSL response curves for a variety of quartz samples extracted from archaeological specimens such as bricks, burnt stones and clay. The GLSL response curve for a sensitive quartz extracted from burnt clay obtained using the multiple aliquot method is shown in Fig. 3A. As seen, the lowest detectable dose for this material is well below 1 mGy.

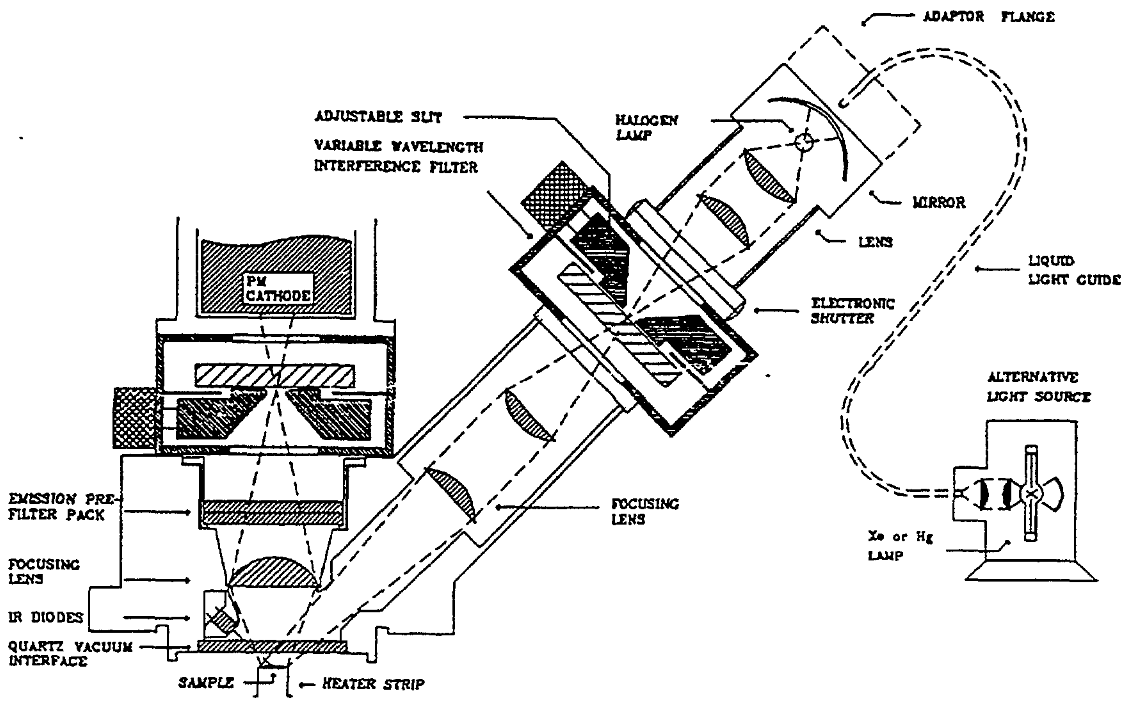


Fig. 1. Schematic diagram of the OSL attachment showing the excitation lamp system with monochromators mounted both on the excitation side and the detection side.

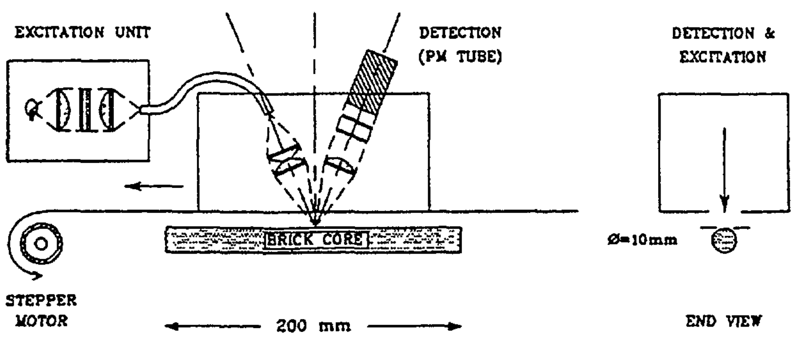


Fig. 2. Schematic diagram of the automatic OSL brick core scanning system.

A single aliquot method was also tested on the same quartz sample as above where the dose response curve was obtained using the regeneration technique. Beta irradiations were carried out using the Sr-90 source of the Risø TL/OSL reader and GLSL measurements were carried out as described above. The results obtained show very little scatter because of the single aliquot technique used where no normalisation is needed. Fig.3B presents the dose versus GLSL response curve in the dose range 0.1 to 5 mGy compared to that of the TL response. The lower detection level using GLSL on this particular sample is seen to be well below 0.5 mGy.

The accumulated "natural" dose induced in quartz by radionuclides contained in modern brick materials and the environmental gamma radiation was measured using GLSL on extracted quartz samples. This experiment was aimed at determining the lower detection limit for an additional dose received by a brick as a result of radioactive release from a nuclear accident taking into account the GLSL contribution from the natural background dose. The quartz grains were extracted from the material and the absorbed dose was determined by GLSL using the additive dose technique. The dose was estimated to be about 200 mGy which is in very good agreement with the expected value based on an annual dose rate of about 5 mGy/y from the environmental radiation and the natural radioactivity in the brick. For this particular brick a lower detection limit for an additional accidental dose would be in the order of 20 mGy (10% above the background).

Depth dose profiles in bricks can be determined by measuring the OSL signals directly from the unseparated material across the brick. Modern bricks were annealed at 500EC to remove any previously acquired TL/OSL signal and then exposed to Co-60 and Cs-137 photon radiation fields, respectively. After irradiation, 8 mm diameter cores were drilled out of the brick and sliced into 1 mm thick circular discs using a diamond saw. Each disc, representing a particular depth in the brick, had their GLSL measured directly from the surface of the unseparated material and as an example the OSL versus depth for an ancient brick irradiated with Co-60 radiation is shown in Fig. 4A. As seen, the half value layer value is about 75 mm which corresponds reasonably well with the expected attenuation of Co-60 photons in brick material. A brick collected from a house in the town Berezyaki in the Chernobyl area was further measured using the same procedure and the GLSL signal corresponding to the natural plus accidental dose versus depth is shown in Fig. 4B. The more rapid attenuation seen here is in contrast to that obtained from the Co-60 irradiation and demonstrates that the Chernobyl brick was exposed to a gamma spectrum with a much higher content of low-energy photons.

The automatic core scanner system was used to measure the dept dose profiles across the 200 mm length of a modern brick exposed in the laboratory to Co-60 and Cs-137 gamma radiation doses, respectively. Ten mm cores were drilled from the brick after irradiation and mounted directly under the light sensing head of the core scanner. The cores were scanned with a speed of 1 mm per sec. using an excitation light density of 20 mW/cm^2. Normalisation was made after bleaching the cores either by exposing the cores by UV light produced by the attached low-pressure Hg lamp or by exposing the cores perpendicularly to a Cs-137 gamma field. Figs 5A and 5B show the dose depth profiles obtained from OSL scanning of cores from a brick that had been exposed from one direction in the laboratory to Cs-137 and Co-60 radiation, respectively (20 Gy). Monte Carlo calculated attenuation curves for the same irradiation geometrics are shown as well and as seen they compare well with the experimentally obtained curves.

Finally, an assessment was made as to whether the OSL technique can be used as an alternative method for the established thermoluminescence technique for measuring accrued dose levels in porcelain: since no heating is required, problems of heat induced sensitivity changes during measurement are overcome. The OSL versus beta dose for a porcelain sample was found to increase linearly with dose in the range 0-16 Gy and shows a further sublinear increase of OSL signal up to at least 200 Gy. These preliminary measurements indicate that dose levels of about 0.1 Gy can be determined using OSL techniques on porcelain. Porcelain samples extracted from outdoor electrical insulators and lamp fittings collected at different locations near the Chernobyl Nuclear Power Plant had their total absorbed doses assessed by OSL. The OSL signals were measured on 8 mm diameter x 1 mm discs made from the samples using green light stimulation. The total doses determined from 6 different specimens varied from about 1 to 3,9 Gy: the highest doses being measured from electrical insulators collected in the Red Forest hot area near the power plant.

4. CONCLUSIONS

Different OSL techniques developed recently at Risø for determining accrued doses in natural materials have been described. These include scanning techniques for assessing depth dose profiles in bricks by measuring OSL directly on the surface of the raw material. Quartz extracted from fired archaeological specimens showed high OSL sensitivity and the lower detection limit for these materials was found to be less than 1 mGy. Porcelain showed interesting OSL properties and the high OSL sensitivity found especially for the glazing layer of e.g. toilet tanks suggests that this particular material can be used with advantage for assessing low accidental doses.

ACKNOWLEDGEMENTS

This work is partly funded by the European Union under the research contract FI3P–CT92–0040.

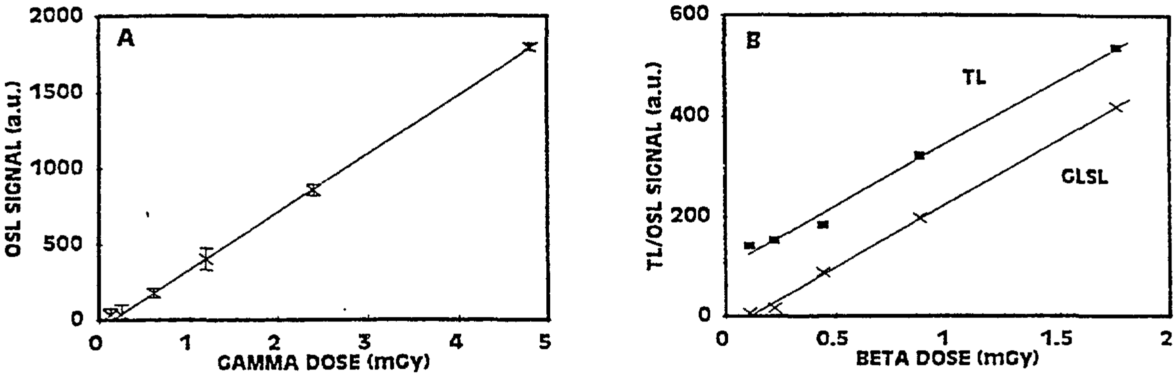


Fig. 3. (A) OSL versus Co-60 gamma dose (multi sample technique) for quartz extracted from a burnt stone. (B) TL and OSL versus beta dose (single aliquot method) for the same quartz sample.

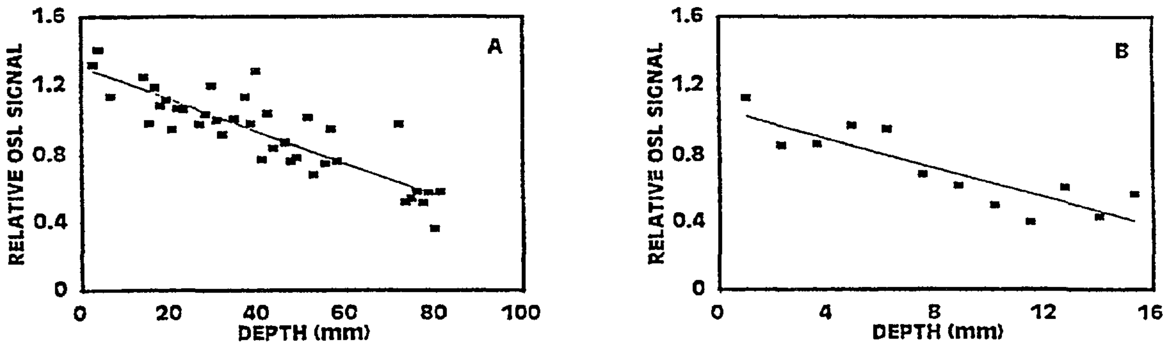


Fig. 4. OSL versus depth into an ancient brick measured with green light stimulation on 1 mm discs drilled and cut through a brick that had been irradiated to 5 Gy Co-60 radiation from one side. (B) OSL versus depth into a brick collected at Chernobyl that had been exposed to the "accidental" dose. Same technique was used as in (A).

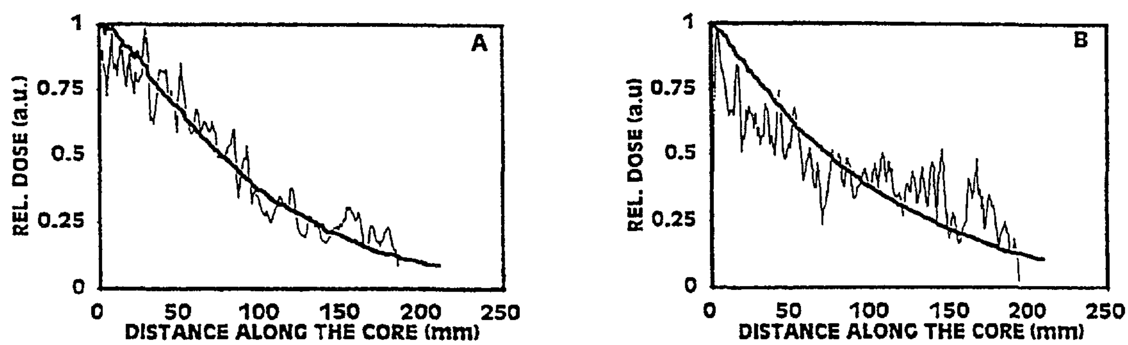


Fig. 5. (A) Relative depth dose profile measured with the automatic OSL scanner on a core from a brick that had been irradiated to 20 Gy Cs-137 gamma radiation from one side. The bold line shows the Monte Carlo calculated attenuation curve for comparison. (B) Same as (A) but for 20 Gy Co-60 gamma radiation.

REFERENCES

[1] BAILIFF, I.K., HASKELL, E.H., The use of the pre-dose technique for environmental dosimetry, Radiat. Prot. Dosim. **6** (1984) 245–248.

[2] BØTTER-JENSEN, L., The automated Risø TL dating reader system, Nucl. Tracks Radiat. Meas. **14** 2 (1988) 177–180.

[3] BØTTER-JENSEN, L., DULLER, G.A.T., A new system for measuring OSL from quartz samples, Nucl. Tracks Radiat. Meas. **20** 4 (1992) 549–553.

[4] BØTTER-JENSEN, L., POOLTON, N.R.J., WILLUMSEN, F., CHRISTIANSEN, H., A compact design for monochromatic OSL measurements in the wavelength range 380-1020 nm, Rad. Meas. (in press) (1994).

[5] GODFREY-SMITH, D.I., HASKELL, E.H., Application of optically stimulated luminescence to the dosimetry of recent radiation events involving low total absorbed doses, Health Physics **65** 4 (1993) 396–404.

[6] HASKELL, E.H., Accident dosimetry using environmental materials: The role of thermoluminescence, Nucl. Tracks Radiat. Meas. **21** (1993) 87–93.

[7] HUNTLEY, D.J., GODFREY-SMITH, D.I., THEWALT, M.L.W., Optical dating of sediments, Nature **313** (1985) 105–107.

[8] STONEHAM, D., The use of porcelain as a low dose background dosemeter, Nucl. Tracks Radiat. Meas. **10** (1985) 509–512.

NUCLEAR EMERGENCY PLANNING AND RESPONSE IN THE NETHERLANDS: EXPERIENCES OBTAINED FROM LARGE SCALE EXERCISES

R.C.G.M. SMETSERS, M.J.M. PRUPPERS, J.F. VAN SONDEREN
National Institute of Public Health and Environmental Protection (RIVM),
Laboratory of Radiation Research,
Netherlands

Abstract

NUCLEAR EMERGENCY PLANNING AND RESPONSE IN THE NETHERLANDS: EXPERIENCES OBTAINED FROM LARGE-SCALE EXERCISES.

In 1986 the Chernobyl accident led the Dutch Government to a reconsideration of their possibilities for managing nuclear emergencies. It was decided to improve both the national emergency management organization and the infrastructure for collecting and presenting technical information. The first improvement resulted in the National Plan for Nuclear Emergency Planning and Response (EPR) and the second in a series of technical facilities for the assessment of radiation doses.

Since 1990, following the implementation of the EPR and most of the technical facilities, several emergency exercises have taken place to test the effectiveness of organization and infrastructure. Special emphasis has been given to the early phase of the simulated accidents. This paper summarises the experiences obtained from these exercises. Major obstacles appear to be: (1) keeping all participants properly informed during the process, (2) the difference in working attitude of technical experts and decision-makers, (3) premature orders for countermeasures and (4) the (too) large number of people involved in the decision-making process. From these experiences requirements for instruments can be deduced. Such instruments include predictive models, to be used for dose assessment in the early phase of an accident which, apart from being fast, should yield uncomplicated results suitable for decision-makers. Refinements of models, such as taking into account the specific nature of the (urban) environment, are not needed until the recovery phase of a nuclear accident.

1. INTRODUCTION

As a reaction to the Chernobyl accident in 1986, the Dutch Government decided to set up a national organization for nuclear emergency planning and response. This resulted in the National Plan for Nuclear Emergency Planning and Response (EPR). EPR describes the procedures and roles of ministries and research institutes during a nuclear accident (VROM 1989; Dal *et al.* 1990). EPR makes a distinction between three different phases in the response to a nuclear incident. In the alarm phase (typically a few hours) the warning message is verified, the threat caused by the accident is assessed and the EPR-organization is activated. In the response phase (typically a few days depending on the actual incident) countermeasures are carried out based on the comparison of dose assessment and pre-set intervention levels. Finally, there is the recovery phase. In this phase, which can take months or even years, the situation is evaluated and - as far as possible - restored to normal.

In emergency situations, the Technical Information Organization deals with the collecting and processing of data and assessing the consequences to support the decision-making process. The structure and tasks of the Technical Information Organization are shown in Figure 1. The national Policy Team, consisting of ministers or high-ranking civil servants, takes decisions on necessary protective actions and co-ordinates the execution of countermeasures. This Policy Team is supported by a number of advisory teams. One of these, the Technical Information Group (TIG), consists of experts (in radiology) representing all organizations and institutes, the so-called Support Centres (SCs), involved in the collection and interpretation of technical information. By comparing the dose assessments, based on either measurements or predictive modelling, with pre-set intervention levels described in the EPR, the TIG advises on protective actions. These are either direct measures such as evacuation, sheltering or iodine prophylactics, or indirect ones, for instance, those for water resources management, and agricultural and food supplies.

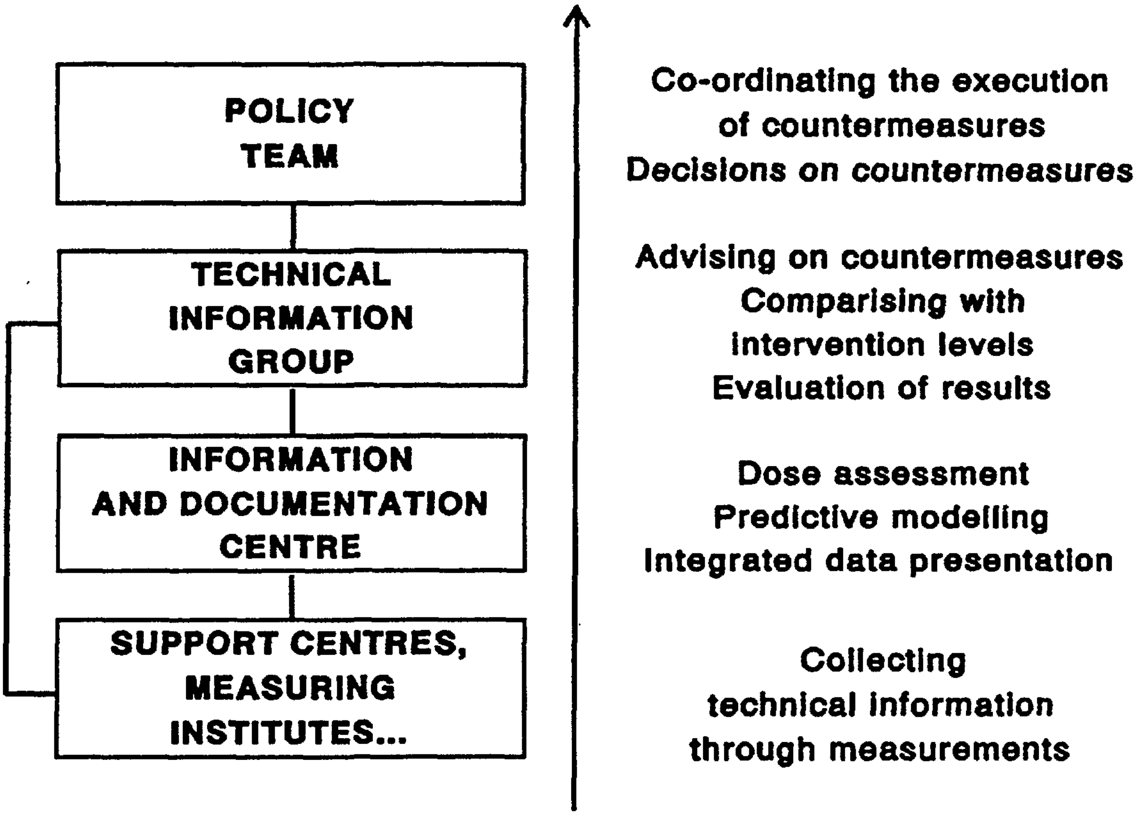


Figure 1 Structure and tasks of the technical information organization.

Along with the implementation of a national emergency organization, the government decided to update the technical infrastructure necessary for an adequate collection and presentation of information during an event. The improvement of the infrastructure resulted in a number of new technical facilities, including several monitoring networks for the surveillance of radiation and radioactivity levels in the environment, food chains and consumer products. Three measuring vans were also acquired (Van Lith *et al.* 1990; Pruppers *et al.* 1991; Smetsers, Van Lunenburg (in press); Van Sonderen (in press)). The development and implementation of both the organization and the technical facilities took place in the period 1987 to 1990.

In the past five years a number of emergency exercises have been carried out. This paper focuses on the experience obtained from these exercises, at least as far as it is relevant for collecting and processing technical information.

2. EXERCISES ON NUCLEAR EMERGENCY PLANNING AND RESPONSE

The following types of exercises, showing an increasing number of personnel and organizational groups, can be distinguished: table top exercises, multi group table top exercises, local scale, national scale and international scale exercises. During table top and multi group table top exercises one or more groups are supposed to test their internal and external procedures. The groups which are not tested are simulated by introducing essential documents into the process of the group or groups-in-training. There are no activities outside the meeting rooms. The first multi group table top exercise took place on December 11, 1990, preceded by a number of table top exercises for the TIG only. The largest National Scale exercise to date took place on November 11, 1991. Although field activities were still limited, almost 500 participants were involved in this drill. The most recent exercise, in collaboration with Belgium, took place on December 2, 1993. This exercise was focused on processes for decision-making, communication and public information at local level; the national level will be tested in the near future during the second phase of this exercise.

All exercises were focused on the *early phase* of an accident at a nuclear power plant. Most scenarios started with a *site emergency* and the threat of a significant release, followed by a major release a few hours later. All emergency exercises were visited and evaluated by independent observers, who advised on further improvement of the EPR organization. The list of remarks was generally lengthy, but most remarks focused on details that were easily followed up by corrective actions. However, some major difficulties were observed repeatedly, and it turned out that the underlying problems could not be solved easily. In other words, these aspects, as listed below, may be inherent in the practice of emergency planning and response.

2.1. The number of people involved

Hundreds of people are involved at all levels of the emergency planning and response organization. To function in this organization, these people have to be informed adequately. During all the emergency exercises it appeared to be very difficult to keep all participants informed properly on the development of the accident itself, the availability of technical information, the latest results on dose assessment in relation to intervention levels, recommendations and decisions on countermeasures to be taken and the actual status of measures already ordered. Sophisticated automatic information systems may be helpful but they cannot solve this problem entirely. This is due, amongst other things, to the amount of information which has to be put into the system, the difficulty of displaying all information in an aggregated form and the fact that several participants do not have easy access to such a system due to their specific job. Within the TIG all relevant information is displayed and kept up to date on old-fashioned bulletin boards. Plenary meetings and the circulation of written information is kept minimal. These procedures have been developed using experience obtained in other countries, in particular from observations of emergency exercises at the Beaver Valley Power Station, Pennsylvania (USA).

2.2. The difference in working attitude of technical experts and decision-makers

The core business of the TIG is to collect all relevant technical information about the accident and pass on a summary of this information, along with recommendations for countermeasures to be taken, to the policy team. In this process, technical information has to be translated into information relevant for decision-makers. The TIG as a group of experts has, on the one hand, adequate knowledge of technical and scientific matters. However, most of its members are less experienced in the field of decision-making. The participants of the policy team, on the other hand, are used to making well-balanced decisions but are, relatively speaking, laymen in the field of radiological protection. The information to be passed on should therefore be clear and comprehensive, and not blurred by unnecessary details and uncertainties which will delay the decision-making process. This is especially important in the early phase of an accident, when quick response is the major demand. For example, sophisticated models for dose assessment may generate dose contours on a very detailed geographical scale, but the announcement of countermeasures such as sheltering, evacuation or iodine prophylactics can only be made on a less detailed scale. The actual boundaries of areas subject to countermeasures are heavily determined by logistic and social considerations.

2.3. The urgent need to 'do something'

In the first hours of an emergency, especially when there is only the threat of a major release, there is not much technical information available. This may be very frustrating, especially for the policy team. During several emergency exercises it appeared that decision-makers did not wait for advice based on technical information but ordered several countermeasures in advance to be sure that they could handle a *worst case* scenario. Part of this problem, however, can be attributed to the scientists participating in the TIG. They have a natural tendency to postpone actual recommendations, awaiting further, more complete information. However, lack of highly sophisticated material, such as high resolution computer plots, may never be an excuse for delay.

2.4. Too many people involved in the decision-making process

Too many people are involved in the decision-making processes, which leads to unnecessary delay. This also holds for the TIG. A reduction of the TIG, limiting its size in the early phase of an accident, is anticipated. Only experts who can advise quickly on interventions aimed at a maximum reduction of the radiation doses received by the general public via the direct pathways of *external irradiation* and *inhalation*, are necessary.

3. DISCUSSION AND CONCLUSIONS

During a nuclear emergency situation technical information is required to perform dose assessments which can be compared with pre-set intervention levels, yielding recommendations for carrying out the most appropriate countermeasures. In the early phase of an accident attention should be focused on rapid assessment of radiation doses received via the direct pathways of external irradiation and inhalation. There is no need for very detailed and sophisticated models leading to apparently accurate dose contours in this phase of an event. Firstly, the uncertainty in the final results, often not validated by measurements, will be considerable anyway, for instance, due to large uncertainties in source terms and release rates. Secondly, copious detail will not further a fast decision-making process; it could even be counterproductive. Recommendations based on technical information should be evaluated on their applicability to decision-making.

Further refinement of models for dose assessment by taking into account the specific characteristics of the urban environment are not needed until the recovery phase. In this phase measures such as sanitation of contaminated areas and return of citizens to regions evacuated in the early phase of the accident are taken. In the recovery phase there is enough time to perform more complex calculations which can also be validated by measurements, and both decision-makers and the general public can be well informed of the results. In this phase it is also easier to direct measures on a more detailed geographical scale. As far as the urban environment is concerned, the relevant exposure pathways are now confined to external radiation from deposited radionuclides and inhalation. Important processes to be modelled now are site specific deposition, (natural) retention, effects of de-contamination, re-suspension and the exchange between the indoor and outdoor environment. Finally, it could be interesting to think about *reverse* intervention levels to support decisions to be made in this phase of the event, for instance, on the basis of dose assessment in a way similar to that in the early phase of an accident.

REFERENCES

[1] DAL, A.H., VAN HIENEN, J.F.A., VAN LITH, D., Nuclear emergency planning and monitoring strategies in the Netherland, Proc. Int. symp. on environmental contamination following a major nuclear incident, Vienna, 16-20 October 1989, IAEA, 1990, IAEA-SM-306/45 (1990) 319–334.

[2] PRUPPERS, M.J.M., MOEN, J.E.T., SMETSERS, R.C.G.M., The role of RIVM in the management of nuclear emergency response, Annual Scientific Report 1990, National Institute of Public Health and Environmental Protection (RIVM), Bilthoven (1991) 144–146.

[3] SMETSERS, R.C.G.M., VAN LUNENBURG, A.P.P.A., Evaluation of the Dutch radioactivity monitoring network for nuclear emergencies over the period 1990–1993, Radiat. Prot. Dosim. (in press).

[4] VAN LITH, D., SMETSERS, R.C.G.M., SLAPER, H., Environmental monitoring and the application of predictive models for nuclear emergencies in the Netherlands, Proc. 2nd REM Workshop on Real time radioactivity monitoring and its interface with predictive atmospheric transport models, Ispra 5–6 December 1989, CEC–JRC Report EUR 12290 EN (1990) 59–74.

[5] VAN SONDEREN, J.F., The Dutch radioactivity monitoring network, CEC workshop on the technical aspects of international exchange of radiological on-line monitoring data, Arona, Italy 1–3 June 1994 (in press) (1994).

[6] VROM, Nuclear Emergency Planning and Response in The Netherlands (EPR), Lower House, Parliamentary session 1988–1989, 21015, Nr.3. Ministry of Housing, Physical Planning and Environment, 90044/2–89 1174/26, The Hague (1989).

XA0054895

FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER (FRMAC), US RESPONSE TO MAJOR RADIOLOGICAL ACCIDENTS

P.G. MUELLER
United States Department of Energy,
Nevada Operations Office,
Las Vegas, Nevada,
United States of America

Abstract

FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER (FRMAC), U.S. RESPONSE TO MAJOR RADIOLOGICAL ACCIDENTS.

During the 1960's and 70's the expanded use of nuclear materials to generate electricity, to provide medical benefits, and for research purposes continued to grow in the United States. While substantial effort went into constructing plants and facilities and providing for a number of redundant backup systems for safety purposes, little effort went into the development of emergency response plans for possible major radiological accidents. Unfortunately, adequate plans and procedures had not been developed to co-ordinate either state or federal emergency response assets and personnel should a major radiological accident occur.

This situation became quite evident following the Three Mile Island Nuclear Reactor accident in 1979. An accident of that magnitude had not been adequately prepared for and Pennsylvania's limited emergency radiological resources and capabilities were quickly exhausted. Several federal agencies with statutory responsibilities for emergency response, including the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), Federal Emergency Management Agency (FEMA), Nuclear Regulatory Commission (NRC), and others provided extensive assistance and support during the accident. However, the assistance was not fully co-ordinated nor controlled.

Following the Three Mile Island incident 13 federal agencies worked co-operatively to develop an agreement called the Federal Radiological Emergency Response Plan (FRERP). Signed in November 1985, this plan delineated the statutory responsibilities and authorities of each federal agency signatory to the FRERP. In the event of a major radiological accident, the FRERP would be activated to ensure that a co-ordinated federal emergency response would be available to respond to any major radiological accident scenario.

The FRERP encompasses a wide variety of radiological accidents, not just those stemming from nuclear power plants. Activation of the FRERP could occur from major accidents involving radiological materials from:

- Nuclear Fuel Cycle Facilities
- Space Craft Launches
- Weapon (Department of Defence or DOE) Transportation
- Weapon Production Facilities
- Spacecraft Re-entry (domestic or foreign)
- Terrorist Incidents
- High-Level Waste Transportation
- Nuclear Power Plants

Key to the FRERP would be the establishment of the Federal Radiological Monitoring and Assessment Center (FRMAC). Development and implementation was assigned to DOE as the agency most capable of providing sufficient resources, assets, and support. In 1987, DOE subsequently assigned programmatic responsibility, with limited funding, to the Nevada Operations Office in Las Vegas, Nevada.

1. RECOGNIZED STATE RESPONSIBILITIES

Under the FRERP the states are clearly established as the recognised and primary decision-maker for any public protective actions required outside the boundaries of the facility ("off-site") experiencing the accident. FRMAC will provide the state(s) with the necessary radiological information so that educated and informed decisions can be made.

Additionally, the FRERP establishes an operational framework through the FRMAC for co-ordinating the radiological monitoring and assessment activities of all federal agencies during a response to radiological emergencies affecting the United States and its territories. The operational FRMAC is the designated federal technical centre for the "on-scene" co-ordination of federal monitoring and assessment activities. FRMAC assets and resources are intended to augment state resources.

FRMAC's purpose and objectives are to provide an organizational structure to monitor and analyse radiological data after a radiation accident and to provide rapid and accurate dose assessment for areas over which radiation has passed, or on which radiation has been deposited. FRMAC assessments and data are provided in total to both the Lead Federal Agency (LFA) and the state.

2. ACTIVATION

Most of the FRMAC response assets are located at the DOE Remote Sensing Laboratory (RSL), Nellis Air Force Base, Las Vegas, Nevada. RSL is operated by EG&G Energy Measurements, Inc. Upon notification, this equipment can be quickly loaded onto military C-141's or C-130's or commercial aircraft. For this reason, FRMAC would typically be located near a large airport. The FRMAC staging and operations facility should be capable of providing a minimum of 10,000 square feet of space.

3. OPERATIONAL FEDERAL ASSISTANCE

In addition to providing monitoring and assessment assistance to the state, FRMAC also provides a wide range of assistance from a number of federal agencies. Since FRMAC operations can employ some 400+ people during a major radiological emergency, federal assistance is designed to ensure that FRMAC activities impact local economies as little as possible.

The monitoring of radiological data from fixed wing and rotary aircraft is among the more sophisticated capabilities of the FRMAC. These state-of-the-art technical instruments can provide the clearest, most defined overall radiological picture of a contaminated area. These Aerial Measurements Survey (AMS) aircraft have already flown hundreds of routine surveys and detection missions. Aerial surveys are among the first and most important radiological survey work conducted by FRMAC during the initial phase of an accident. Existing AMS instrumentation and equipment can be affixed to U.S. military aircraft and foreign aircraft, if necessary.

Predictive fallout patterns are available to the FRMAC from the Lawrence Livermore National Laboratory (LLNL), Atmospheric Release Advisory Capability (ARAC) models. ARAC was instrumental in determining the fallout patterns associated with the Chernobyl accident in 1986. This capability is present and available during any FRMAC operation via a dedicated phone line to the LLNL computer. ARAC models can be augmented with the use of other radiological predictive models available from the NRC, the National Oceanic and Atmospheric Administration (NOAA), as well as utilities and states.

FRMAC assets include extensive communication equipment. The FRMAC can independently operate nearly 300 telephones with a satellite hook-up to the INMARSAT (International Maritime Satellite) system. As a result, this system would have no impact on the local telephone system. In time, FRMAC will ensure that direct microwave communication links are established between the FRMAC, the state's Emergency Operations Facility, and FEMA's Disaster Field Office.

4. FRMAC FIELD ORGANIZATION

Figure 1 depicts the FRMAC Field Organization. This organizational structure has been developed and adapted from those used in many exercises, including federal full-field, nuclear power plant, and FRERP exercises. The complete chart of key personnel, indicated on the figure, represents the requirements needed to implement FRMAC operations in the event of a large, full-scale deployment. In the event of a smaller incident, the FRMAC field organization would remain the same; however, some job functions might be combined, since fewer professionals and assets would be necessary to augment state resources and personnel.
The FRMAC Director is a DOE/NV-appointed senior DOE official designated with the responsibility of managing a FRMAC. The FRMAC director co-ordinates and directs all FRMAC personnel who may be provided by any DOE Operations Office, contractor, or other federal or *state* agencies. It is the responsibility of the FRMAC director to provide information to both the state and the LFA, simultaneously.

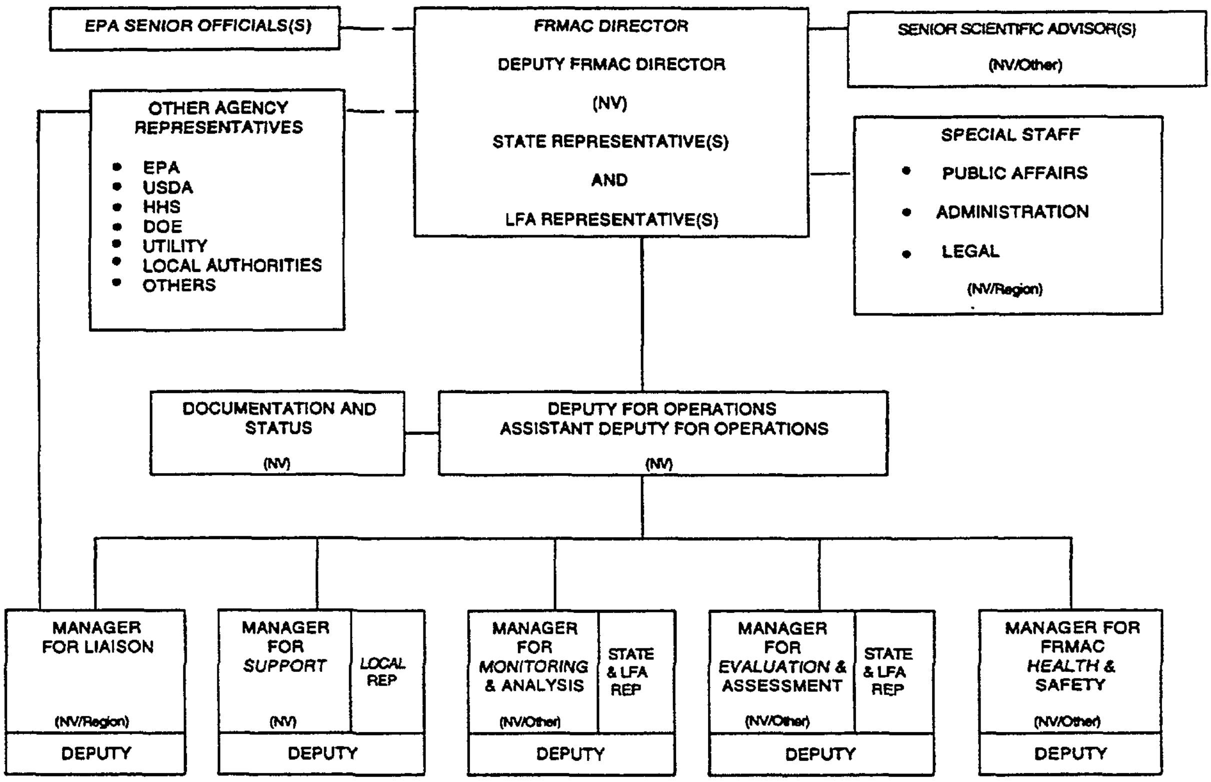


FIG. 1. FRMAC ORGANIZATION

Another key position within the FRMAC is that of the Senior Scientific Advisor, who provides the FRMAC Director with an independent overview of the radiological condition and environmental impact of the radiological accident. This individual would typically be highly respected expert in the field of radiation health and safety.

A host of high-level managers from a variety of federal agencies and associated contractors are available to provide operational support and logistics, monitoring and analysis, radiological evaluation and assessment, and radiation worker safety. FRMAC also provides a manager to ensure that proper liaison and co-ordination with other state, federal, and utility are open.

5. FRMAC TODAY

To ensure that FRMAC activities, documentation, science, and training needs are met, seven working groups and a management panel meet on a regular basis. These working groups oversee specific areas and guarantee that FRMAC stays as close as possible to the state of the science. Working groups are chaired by either DOE or DOE contractors. They are specialists from a variety of federal agencies, contractors, and the Conference of Radiation Control Program Directors (CRCPD).

The working groups are:

- Operations
- Evaluation and Assessment
- Monitoring and Analysis
- Health and Safety
- Training
- Exercises
- Post-Emergency

It is important that FRMAC be consistent in its use of equations, calibrations, sampling methods, and assessment techniques. For this reason, both the Evaluation and Assessment working group and the Monitoring and Analysis working groups have completed draft manuals which will provide standard procedures for FRMAC operations.

All environmental radiological data collected by the FRMAC will be accumulated in its data centre. This centre is designed to be comprehensive, and will contain all of the off-site environmental radiological data and associated details making the information traceable and accountable. The data will be traceable to individual teams, team leaders, measurement locations, instruments, calibrations, and standards. This data centre maintains a network of computers which provide immediate results of collected data to health physicists from both the state and federal government.

All radiological data can then be transferred directly to FRMAC's state-of-the-art Geographic Information System for display on a variety of maps. These maps contain information surrounding the accident scene, such as the locations of schools, hospitals, evacuation routes, land cover, hydrology, roads, and other valuable information regarding a site. Colour hard copy is available at the push of a button.

6. SUMMARY

The accident at Three Mile Island taught this nation an important lesson regarding radiological emergency response. Emergency response and the preparation for it is as necessary as the energy radiation provides. The implementation of FRMAC and the federal plan from which it was borne have become synonymous with co-operation among the many federal agencies and the states. It is a response mechanism which must be planned for and available if ever needed.

XA0054896

THE EMERGENCY RADIOLOGICAL MONITORING AND ANALYSIS DIVISION OF THE UNITED STATES FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER

D.J. THOMÉ
EG&G Energy Measurements, Inc.,
Las Vegas, Nevada,
United States of America

Abstract

THE EMERGENCY RADIOLOGICAL MONITORING AND ANALYSIS DIVISION OF THE UNITED STATES FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER.

The U.S. Federal Radiological Emergency Response Plan (FRERP) provides the framework for integrating the various Federal agencies responding to a major radiological emergency. The FRERP authorises the creation of the Federal Radiological Monitoring and Assessment Center (FRMAC), which is established to co-ordinate all Federal agencies involved in the monitoring and assessment of the off-site radiological conditions in support of the impacted States and the Lead Federal Agency (LFA). Within the FRMAC, the Monitoring and Analysis Division is responsible for co-ordinating all FRMAC assets involved in conducting a comprehensive program of environmental monitoring, sampling, radioanalysis, and quality assurance. This program includes:

1. Aerial Radiological Monitoring — Fixed-Wing and Helicopter
2. Field Monitoring and Sampling
3. Radioanalysis — Mobile and Fixed Laboratories
4. Radiation Detection Instrumentation — Calibration and Maintenance
5. Environmental Dosimetry
6. Integrated program of Quality Assurance

To assure consistency, completeness, and the quality of the data produced, a methodology and procedures manual is being developed. This paper discusses the structure, assets, and operations of the FRMAC Monitoring and Analysis Division and the content and preparation of the manual.

1. INTRODUCTION

For radiological emergencies occurring within the United States, the State or local governments have the primary responsibility for assuring the health and safety of the public and minimising the impact on the environment. If the off-site response to an emergency exceeds State and/or local resources, assistance may be requested from the Federal government. The U. S. Department of Energy (DOE) has the responsibility for providing the initial off-site radiological monitoring and assessment assistance. The DOE may respond to a State's request for assistance by deploying a Radiological Assistance Program (RAP) team from the appropriate DOE region. If the emergency requires more assets than RAP can provide, a Federal Radiological Monitoring and Assessment Center (FRMAC) can be established.

The focus of the FRMAC is to provide radiological monitoring and assessment support, data interpretations, and dose projections to the State(s) and the Lead Federal Agency (LFA), and to maintain a common set of quality assured environmental data. The FRMAC can be a large organization comprised of a professional staff of 300 or more individuals from many different agencies.

2. MONITORING AND ANALYSIS

Within the FRMAC, the Monitoring and Analysis Division (M&A) has the responsibility for co-ordinating all FRMAC assets involved in conducting a comprehensive program of environmental radiological monitoring, sampling, radioanalysis, and quality assurance.

This program includes:

- Aerial Radiological Monitoring — Fixed-Wing and Helicopter
- Field Monitoring and Sampling
- Radioanalysis — Mobile and Fixed Laboratories
- Radiation Detection Instrumentation — Calibration and Maintenance
- Environmental Dosimetry
- Integrated Program of Quality Assurance

The M&A must assure that all monitoring, sampling, and laboratory activities are accomplished in a manner which meets FRMAC requirements and that all monitoring measurements, sample collections, and derived analytical data are scientifically defensible, of acceptable known quality, and in consistent units.

Early in an emergency, monitoring data will be scarce, but urgently needed as a basis for protective actions. The flow of data is expedited to put the data into the possession of the decision makers as quickly as possible. Monitoring instructions are transmitted via radio to the field monitoring teams by Net Control. The field monitoring teams transmit the radiological data to the Data Acquisition Officer, who transcribes the data on pre-established forms. The forms are than quickly reviewed by the Field Data Specialist for completeness, reasonableness, and proper units. The data are hand plotted by M&A's Status Map Co-ordinator. The reviewed forms are photocopied, stamped as raw data, and distributed to the Evaluation and Assessment Division (E&A), the Geographical Information System (GIS), and all other interested parties including Federal, State, local, and LFA representatives located at the FRMAC. The original copy of all data forms is documented and archived in the FRMAC's comprehensive and traceable data base.

Radioanalytical laboratory data are managed similarly to the field monitoring data. Environmental samples are received and managed by Sample Control. Analytical data are reviewed for completeness, reasonableness, and proper units by the Analysis Specialist prior to distribution to E&A and the FRMAC community.

Priorities for M&A are established and constantly re-evaluated by the FRMAC's Senior Scientific Advisor, the E&A Manager, and the M&A Manager. These three individuals, in concert, continually evaluate the FRMAC requirements identified by the State(s) and the LFA against the M&A resources and adjust priorities accordingly. If a conflict arises, it is referred, via the FRMAC Director, to the State(s) and the LFA for resolution.

The M&A Manager is responsible for the overall management and direction of M&A. Representatives to M&A from the State(s) and LFA are extremely valuable. Because of their local and professional knowledge and their personal relationships, they provide great assistance in the efficient and optimal operation of M&A.

2.1. Aerial Measuring System

Both fixed-wing and helicopter aircraft can be used for radiological monitoring. Upon arriving at the location of a radiological emergency where deposition has occurred, the radiological monitoring aircraft fly a serpentine pattern traversing the predominant plume footprint and a circle with a radius of 16 km (10 mi) centred at the emergency site. During flight, cursory radiological data such as the spectral summation count rate relative to the background and the dominant isotopes can be identified and radioed to ground control. Upon landing, the data tapes are transferred to an on-scene mobile computer laboratory for processing. The lower levels of detection of the aerial measuring systems are in the range of one microroentgen per hour above the background level. The mission for this initial flight is to determine:

- Direction and approximate exposure rates along the deposition center line
- Outline of contamination footprint
- Major isotopes

2.1.1. Fixed-Wing Aircraft

To map radioactive deposition, fixed-wing aircraft are equipped with two 4x4x16-inch rectangular thallium-activated sodium iodide, NaI(Tl), gamma detectors. Each second a gamma spectrum, approximately 40 thousand electron volts (keV) to 3 million electron volts (MeV), is acquired and simultaneously, the latitude, longitude, altitude, date and time of day, barometric pressure, and temperature are recorded. The data are partially analysed on board and stored on magnetic tape cartridges for detailed analysis upon landing (EGG,1985).

2.1.2. Helicopters

For detailed radioactive deposition mapping, helicopters are equipped with two instrument pods mounted to the skid struts. Each pod contains four 4x4x16-inch rectangular NaI(Tl) gamma detectors plus one shielded 2x4x4-inch NaI(Tl) detector. The large detector array is exposed to the entire gamma radiation field and the shielded detector is upward looking to provide a measure of the airborne and cosmic radiation. As the spectra are multiplexed from all eight detectors, one of the eight detectors is also routed to a separate analogue-to-digital converter. This independent spectral acquisition provides the ability to acquire spectra in radiation fields that are sufficiently intense to overload the eight-detector array (Riedhauser,1994).

Products that are available from aerial mapping include:

- Isodose and exposure contours calculated to one meter above the ground.
- Surface deposition of specific radionuclides.
- Total activity inventories of radionuclides of interest.
- Gamma-ray energy spectra.
- The M&A provides these products to E&A to be included in the assessment process, digitised, entered into the GIS, and distributed to all users of the data.

2.2. Field Monitoring and Sampling

FRMAC monitoring personnel will arrive on scene with the appropriate instrumentation for monitoring the type of radiological emergency at hand. For a mixed fission product release or an unknown gamma emitting radionuclide contaminant, the intrinsic germanium in-situ gamma spectroscopy systems provide a fast, accurate method of determining isotopic ratios and deposition concentrations. The intrinsic germanium gamma detectors are equipped with beryllium windows to allow the acquisition of photons with energies as low as 10 keV. This makes possible the detection of transuranics such as plutonium–238, plutonium–239 and americium–241. Specialised instruments such as Field Instruments for the Detection of Low Energy Radiation (FIDLER) are available for emergencies involving nuclear weapons or spacecraft using plutonium–238 radiation thermal generators.

Instrument repair equipment plus an irradiator and various traceable radioactive sources are deployed for calibration and maintenance of the field radiation detection instrumentation. To maximise the comparability of the radiological data acquired by the various organizations, this calibration capability is available to the State(s), the LFA, and any other group involved in radiological monitoring.

Environmental sampling equipment and supplies which will arrive along with the FRMAC main party include:

- Low and high volume air samplers for particulate and reactive gases.
- Whole air samplers for noble gas analysis.
- Specialised sampling tools for reproducible, well-defined soil and sediment samples.
- Equipment for sampling vegetation and produce.
- Equipment for sampling water and milk.

Chain-of-Custody procedures are followed during all sample collection and handling activities. The integrity and accountability of every sample is ensured by documenting that it is in the possession of a responsible person or it is secured in an acceptable manner.

Accurately knowing the physical locations of field measurements and sample collections is critical to a meaningful characterisation of the emergency situation. All such locations are identified in three ways. The latitude and longitude is determined, the street orientation is noted, and the sector/distance is defined. To determine the latitude and longitude, the field monitoring teams are equipped with Global Positioning System (GPS) units. The street orientation is defined by the street address, street intersections, mile markers, or odometer readings from some well defined landmark. Sector refers to the partitioning of the area about the emergency site into 16–22.5 degree sectors. The distance is calculated as the distance from the emergency site to the monitoring location. The sector/distance information allows the Status Map Co-ordinator to rapidly locate and identify a monitoring or sampling site on the status map.

2.3. Radioanalysis — Mobile and Fixed Laboratories

FRMAC has access to both mobile and institutional (fixed) radioanalytical laboratories for the analysis of environmental samples. Although FRMAC does not possess mobile laboratories, they are provided with trained staff by various federal agencies and federal agency contractors. The mobile laboratories associated with a FRMAC provide a rapid initial qualitative and quantitative estimate of the radionuclides of interest. For a more detailed analysis and/or for analyses beyond the capability of the mobile laboratories, samples are shipped to fixed laboratories. Analytical techniques available from most mobile laboratories include:

- Gamma spectroscopy.
- Gross alpha and beta.
- Liquid scintillation counting.

2.4. Environmental Dosimetry

For most radiation emergencies, thermoluminescence dosimeters (TLDs) provide a convenient, easily-deployable method for measuring and documenting integrated radiation exposure levels at various locations and radiation doses to residents and other personnel in the off-site areas.

2.5. Quality Assurance

Having an estimate of the quality of the data that are being used as a basis for protective actions is of paramount importance. The resources devoted to quality assurance (QA) depend largely on the stage of the emergency. In the early stages of a radiological emergency, when the impact on the health and safety of the public is not well defined, the amount of FRMAC resources devoted to QA will be the minimum that will assure the acceptable quality of the data for the use it is intended. As the emergency stabilises, the resources dedicated to QA will increase to approximately 20 percent (EPA,1987).

3. MONITORING AND ANALYSIS MANUAL

To assure consistency, completeness, and the quality of the monitoring and analytical data produced by the FRMAC, a methodology and procedures manual is under development. The manual will address:

- Field monitoring procedures applicable to radiological emergencies.
- Environmental sample collection procedures.
- Environmental sample preparation and analysis procedures applicable for mobile laboratories
- Standard reporting units
    - XQuality Assurance.
    - XMonitoring instrumentation calibration and maintenance

Initially, methods and procedures were obtained from many different sources. These sources included the Department of Energy, U.S. Environmental Protection Agency, national laboratories, and various States. An attempt is being made to identify the "best" methods available. The criteria for "best" are:

- Scientifically defensible
- Simple
- Applicable to a FRMAC deployment
- Most likely be adopted by others

It should be emphasised that the procedures are intended for use in responding to an emergency and processing relatively large numbers of samples in the shortest possible time. Therefore, in some cases, they represent a compromise between precise analytical determinations and determinations satisfactory for emergency response activities.

A partial first draft of the manual has been completed and the first working draft should be available by late summer or early fall of 1994. Our expectation is that once it is available to the emergency response community, many constructive modifications will be identified. For this reason, we are expecting to reissue this manual annually for the first few years, and later as dictated by improvements in technology and/or changes in policy.

4. CONCLUSION

The FRMAC team is a cadre of highly trained, experienced scientists, technicians, and support personnel from many different agencies, all working together during a major radiological emergency to support the State(s) and the LFA. The foundation of the FRMAC is the Monitoring and Analysis Division. This Division, using state-of-the-art technology and methodology, provides the radiological monitoring and analytically derived data that are the basis for protective actions for the public.

REFERENCES

[1] EPA, Data Quality Objectives for Remedial Response Activities, (EPA/540/G87/003), March (1987).

[2] DOE, Federal Radiological Emergency Response Plan (FRERP), Agency Co-ordinating Draft, March (1994).

[3] FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER (FRMAC), FRMAC Operations Plan, Emergency Phase, Working Draft #1, DOE (DOE/NV-XXX, FRMAC–11– 93,UC–707) May (1993).

[4] Remote Sensing Technology, Proceedings of a Symposium on Remote Sensing Technology in Support of the United States Department of Energy, Las Vegas, Nevada; EGG-10282-1057, 23–25 February (1983).

[5] RIEDHAUSER, S.R., An Aerial Radiological Survey of the Sandia National Laboratory and Surrounding Area. Las Vegas, NV:EG&G Energy Measurements, EGG 11265–1030 (1994).

EVALUATION AND ASSESSMENT METHODOLOGY, STANDARDS, AND PROCEDURES MANUAL OF THE UNITED STATES FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER

XA0054897

K.C. KERNS, Z.G. BURSON
EG&G Energy Measurements, Inc.,
Remote Sensing Laboratory,
Las Vegas, Nevada

J.M. SMITH
USEPA, National Air and Radiation Environmental Laboratory,
Montgomery, Alabama

R.L. BLANCHARD
Sanford Cohen and Associates, Inc.,
McLean, Virginia

United States of America

Abstract

EVALUATION AND ASSESSMENT METHODOLOGY, STANDARDS, AND PROCEDURES MANUAL OF THE UNITED STATES FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER.

In the event of a major radiological emergency, the U.S. Federal Radiological Emergency Response Plan authorises the creation of the Federal Radiological Monitoring and Assessment Center (FRMAC). The FRMAC is established to co-ordinate the Federal off-site monitoring and assessment activities, and is comprised of representatives from several Federal agencies and Department of Energy contractors who provide assistance to the state(s) and Lead Federal Agency.

The Evaluation and Assessment (E&A) Division of the FRMAC is responsible for receiving, storing, and interpreting environmental surveillance data to estimate the potential health consequences to the population in the vicinity of the accident site. The E&A Division has commissioned the preparation of a methodology and procedures manual which will result in a consistent approach by Division members in carrying out their duties. The first edition of this manual is nearing completion. In this paper, a brief review of the structure of the FRMAC is presented, with emphasis on the E&A Division. The contents of the E&A manual are briefly described, as are future plans for its expansion.

1. INTRODUCTION

The Federal Radiological Emergency Response Plan (FRERP) was developed in response to the Three Mile Island Nuclear Power Generating Station accident on March 29, 1979. The Federal response to that accident pointed out the need for a co-ordinated response plan. The FRERP was formalised on November 8, 1985, and was signed by those Federal Agencies having responsibilities during a radiological emergency. The FRERP establishes the Federal Radiological Monitoring and Assessment Center (FRMAC) as the technical operations centre for all Federal off-site monitoring and assessment activities. The FRMAC is comprised of representatives from several Federal agencies and Department of Energy (DOE) contractors, which assemble to co-operatively provide assistance to the state(s) and the Lead Federal Agency (LFA) during a significant radiological emergency.

2. FEDERAL RADIOLOGICAL MONITORING AND ASSESSMENT CENTER (FRMAC)

The primary objective of the FRMAC is to provide to the state(s) and the LFA radiological monitoring and assessment support, data interpretation, dose projections, and to maintain a common set of quality assured environmental data. The size of the FRMAC response will depend on the size and nature of the emergency. A FRMAC may be as large as 300 or more personnel.

The FRMAC organizational structure consists of the FRMAC management and five divisions: Liaison, Support, Health and Safety, Monitoring and Analysis, and Evaluation and Assessment.

The Liaison Division co-ordinates all FRMAC liaisons assigned to the various state, local, facility, and LFA emergency operations centres. The Liaison Division also co-ordinates all the FRMAC representatives from other organizations. The Support Division provides all the necessary support to sustain a fully operational FRMAC including communications, electrical work, transportation, video and photography, logistics, security, and administrative services. The Health and Safety Division provides for the safety and well-being of FRMAC workers. Health and Safety personnel evaluate the working environment and provides guidance in the areas of health physics, industrial hygiene, occupational safety, and medical care. The Monitoring and Analysis (M&A) Division co-ordinates all the FRMAC assets involved in environmental radiological monitoring, sampling, radioanalysis, and quality assurance. The monitoring and sampling data are subjected to a cursory quality assurance check then provided to the Evaluation and Assessment group and distributed within the FRMAC.

3. EVALUATION AND ASSESSMENT DIVISION

The Evaluation and Assessment (E&A) Division within the FRMAC is responsible for establishing a comprehensive and accountable data base for accident-related environmental surveillance data, evaluating this data, and assessing the potential significance and impact of the emergency on public health using this information. To accomplish these objectives, the Division is organised into five functional groups:

The Predictions Group prepares predictions of plume concentrations, ground deposition, and potential doses to individuals and populations resulting from the release of radioactive materials. These predictions are particularly useful during the period before substantial measured environmental data are available upon which to base assessments.

The Data Management Group reviews all incoming data from the FRMAC M&A Division, as well as all available non FRMAC-generated radiological monitoring data. After the data sheets are screened for consistency and completeness, they are copied and widely distributed within the FRMAC. The original data sheets are maintained in an archive and are closely controlled. The data are entered into a comprehensive, computerised database and displayed on a Geographical Information System (GIS).

The Assessment Group uses measured environmental data and dose calculation models to estimate potential doses to the public in the impacted area. The group uses these data projections to estimate geographical areas where various protective actions should be considered to mitigate potential doses and to support decisions related to the initiation of recovery actions.

The Overview Group provides input to the Assessment and Data Management Groups relative to output format, graphics, and overall assessment perspectives. The final

FRMAC products are generated by the Overview Group and, after an internal review, are released to the state(s) and the LFA by the FRMAC Director.

The Meteorology Group provides weather information for FRMAC operations, field monitoring, sample collection, and aerial surveys.

When measured environmental radiological data are available, a wide variety of issues are considered by the staff in the E&A Division to estimate doses. These include plume characterisation, estimation of ground deposition and ground shine external doses, external immersion doses, inhalation from a passing cloud and/or resuspension, ingestion pathway transfer factors, consumption rates and doses, occupancy rates, etc. The E&A dose projections will be as realistic as possible, using reasonable assumptions and parameter values which are judged to be appropriate after consideration of the uncertainties involved in the data and the computational models. The assumption and parameter values will be documented, and their sources referenced and included in the assessment.

4. EVALUATION AND ASSESSMENT MANUAL

The E&A Division has drafted a manual which specifies the procedures, standards, and calculational methodology which will be applied in fulfilling the Division role in the FRMAC. The draft has been used at four major FRMAC exercises and revisions have been made based on these experiences.

The manual is oriented toward estimates for short-term (acute) exposures which might be encountered during the initial phase of an accidental release. The models are simple and intended to be used in hand calculations. However, it is planned that the methodology will be expanded in the future for personal computer (PC) applications.

The E&A Division manual will be used to: 1) Facilitate the assessment, by E&A Division members, of the consequences of accidental radionuclide releases, including comparing projected doses to pre-established protective action guidelines (PAGs); 2) Document procedures used in assessments by E&A Division members, 3) Provide consistency in assessments performed by different E&A Division members during around-the-clock FRMAC operations; 4) Serve as a training document for E&A Division members, as well as other members of FRMAC and interested participants from Federal and state agencies; 5) Provide a sound technical base for assessments agreed to and accepted by the technical community before the accident; and 6) Facilitate the possible adoption of the manual by other emergency response groups, including those outside the United States. If the manual is used by international emergency response personnel, this will help to assure the consistent interpretation of dose assessment data for international incidents.

Emphasis is placed on making the manual clear and easy to use, especially under emergency conditions when there will be pressure to produce answers quickly. The manual is divided into a main body of material, which will be used most frequently, and several appendices, containing supporting information and models used less frequently.

BODY OF MANUAL

The body of the document contains models for direct determination of radiation doses based on measured environmental radiation, a brief summary of the Environmental Protection Agency (EPA) and Food and Drug Administration (FDA) Protective Action Guides (PAGs), and information on the effectiveness of dose mitigation techniques.

Exposure Pathway Models

Cloud Passage For an airborne release, techniques for making inhalation and air submersion dose estimates based upon measured air concentrations during cloud passage.

Ground Contamination Information necessary to predict widespread isotopic distributions using external gamma-ray measurements based on the relationship between the gamma-ray intensity and isotopic distributions determined at a few locations. The techniques will only be valid in cases in which the radionuclide ratios on the ground remain relatively constant between geographically separated locations.

Resuspension Estimation of inhalation and external air submersion doses, based upon measured ground or airborne radionuclide concentrations, for both near-field and far-field locations.

Liquid Pathways Estimation of doses due to the ingestion of contaminated drinking water using methods based upon measured radionuclide concentrations in water.

Fresh Food Products Methods to estimate doses due to the ingestion of contaminated leafy vegetables, cows' milk, and goats' milk. The leafy vegetable methodology is based on having measured radionuclide concentrations in vegetation. The cows' milk and goats' milk methodology is based on having measured radionuclide concentrations in milk, or in animal forage and drinking water. Special models are provided for tritium, strontium–89/90, iodine-131/133, and cesium-134/137 in milk.

Protective Action Guides (PAGs)

EPA and FDA have established PAGs for the early phase of an atmospheric release, food and water during the intermediate phase, deposited radioactive materials during the intermediate phase, and emergency worker exposure.

At the present time the manual is being revised to include more information on rapid procedures in comparing projected doses to the EPA and FDA PAGs.

Dose Mitigation Measures

This section provides information on the effectiveness of various dose reduction methodologies that have a sound technical basis and that can be applied to the basic dose calculations described in previous sections of the manual.

5. APPENDICES

The appendices discuss dose coefficients, information on the removal of radionuclides by water treatment and during food preparation, airborne transport of radionuclides using atmospheric dispersion modelling, transport of radionuclides in surface waters, environmental transport and dose calculations for the fresh food pathways based on source term data and airborne dispersion, half-lives and decay constants of principal radionuclides, and example dose calculations.

6. FUTURE PLANS

The manual has undergone two major reviews and has been tested at four major exercises by members of the FRMAC E&A Division. A major revision is underway which will be completed by the fall of 1994. After this draft is reviewed by E&A Division members and their comments are incorporated, the document will be released to other Federal and state agencies for external review. Following the completion of all reviews, and incorporation of comments, the manual will be published in final form, subject to review and revision biennially.

REFERENCES

[1] Manual of Protective Action Guides and Protective Actions for Nuclear Incidents, EPA 400–R–92–001. U. S. Environmental Protection Agency, Office of Radiation and Indoor Air, Washington, D.C. (1992).

[2] FRMAC Operations Plan, Emergency Phase (Working Draft #1), FRMAC-11-93. U.S. Department of Energy, Nevada Operations Office, Las Vegas, Nevada (1993).

REAL-TIME MODELLING OF COMPLEX ATMOSPHERIC RELEASES IN URBAN AREAS

R.L. BASKETT
EG&G Energy Measurements, Inc.,
Pleasanton

J.S. ELLIS, T.J. SULLIVAN
Lawrence Livermore National Laboratory,
Livermore

California, United States of America

Abstract

REAL-TIME MODELLING OF COMPLEX ATMOSPHERIC RELEASES IN URBAN AREAS.

If a nuclear installation in or near an urban area has a venting, fire, or explosion, airborne radioactivity becomes the major concern. Dispersion models are the immediate tool for estimating the dose and contamination. Responses in urban areas depend on knowledge of the amount of the release, representative meteorological data, and the ability of the dispersion model to simulate the complex flows as modified by terrain or local wind conditions. A centralised dispersion modelling system can produce realistic assessments of radiological accidents anywhere in a country within several minutes if it is computer-automated. The system requires source-term, terrain, mapping and dose-factor databases, real-time meteorological data acquisition, three-dimensional atmospheric transport and dispersion models, and experienced staff. Experience with past responses in urban areas by the Atmospheric Release Advisory Capability (ARAC) program at Lawrence Livermore National Laboratory illustrate the challenges for three-dimensional dispersion models.

1. INTRODUCTION

The first step in responding to a radiological release to the atmosphere involves using computer models to determine the extent of contamination. Dispersion models can help during the initial response in two key ways. First, emergency managers can use dispersion models results to advise the public to stay indoors or evacuate if necessary. Second, models can estimate the amount of nuclear material which has been deposited on the surface of buildings or the ground. Monitoring teams can use the modelled deposition pattern to initiate radiological field surveys which will in turn be used to determine initial exposures and health impacts, identify areas for contamination control and ultimately plan the accident clean-up. In addition, if the source is gaseous or if it is diluted below instrument detection limits, models will likely be the only method to quantify health concerns.

Potential sources of large radiological releases include nuclear power plants, and nuclear fuel processing and storage facilities. Other lessor risks include nuclear-powered ships or submarines or nuclear-powered satellite re-entry and burn-up. Smaller sources include transportation of nuclear fuels, industrial and university research reactors, other research facilities, and hospitals. Emergency preparedness requires the careful consideration of source inventories, possible pathways to the air, the nuclides involved, and their combined dose via inhalation, immersion, ingestion, and groundshine pathways.

In the mid-1970s the U.S. Atomic Energy Commission, now the U.S. Department of Energy, decided that a national center would be a cost-effective way to provide advisories for significant accidental releases of nuclear material anywhere in the country. For two decades, the ARAC program has evolved with that purpose and has been integrated with several federal organizations including the Federal Radiological Monitoring and Assessment Center (FRMAC). Some notable ARAC responses include Three Mile Island, Chernobyl, the oil fires in Kuwait, and the eruption of Mt. Pinatubo in the Philippines (Sullivan et al. 1993).

2. THREE-DIMENSIONAL DIAGNOSTIC DISPERSION MODEL

The ARAC emergency response center in Livermore, California produces timely and credible calculations by employing several dispersion models integrated with real-time world-wide meteorological data links, on-line source-term, topographic, geographic, and dose databases. ARAC's core mesoscale models are the three-dimensional, diagnostic, finite-difference computer codes shown in Figure 1. The typical model run takes about 10 min of Digital Equipment Corporation (DEC) VAX 6610 CPU time at 35 million instructions per second (Mips) to complete, including the automated preparation of the input files.

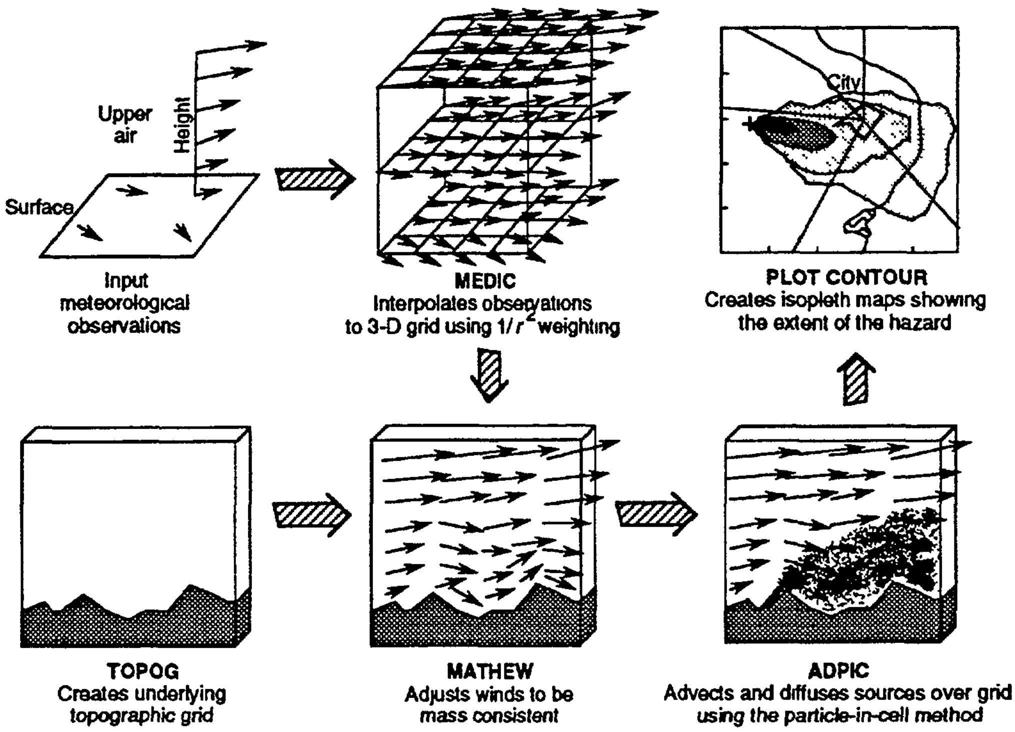


Figure 1. ARAC's primary diagnostic emergency response dispersion model run stream

For a response a grid is chosen and the underlying block-cell terrain is built from an on-line database with 0.5 km resolution using the TOPOG code. The system automatically acquires meteorological data surrounding the accident location anywhere in the world via a dedicated link to the U.S. Air Force Global Weather Center. These wind-speed and direction observations are first interpolated over the chosen grid by the Meteorological Data Interpolation (MEDIC) code using an inverse-distance-squared ($1/r^2$) weighting of the data and wind-profile laws. The effects of terrain and atmospheric stability on the wind field are determined by the Mass-adjusted the Winds (MATHEW) code which creates a mass-consistent, nondivergent flow field over the grid. Vertical velocities are generated by enforcing the mass conservation (or continuity) equation on each grid cell, ensuring that the same amount of air leaves each box as enters it.

MATHEW provides the mean winds for Atmospheric Dispersion by Particle–in–Cell (ADPIC), a nested-grid dispersion model. Tens of thousands of marker particles are available to represent as many different sources or nuclides as necessary in a single model run. Dispersion of the marker particles can be described by two basic processes: transport by the mean wind and diffusion by turbulence. Rates of horizontal and vertical diffusion, which vary in space and time, are computed using empirical equations.

Primary accidental release mechanisms for nuclear accidents include ventings, fires and explosions. Fires or explosions can eject material vertically from several hundred meters to several kilometres. Time-dependent plume rise is controlled by the amount of heat energy released, the height of the inversion, the stability of the atmosphere, and the wind-speed profile in the planetary boundary layer. Radioactive decay, particle-size-dependent gravitational settling, dry deposition, and precipitation scavenging are computed as the material is transported and diffused. A uniform inversion height and atmospheric stability are specified over the model domain but can be changed as a function of time.

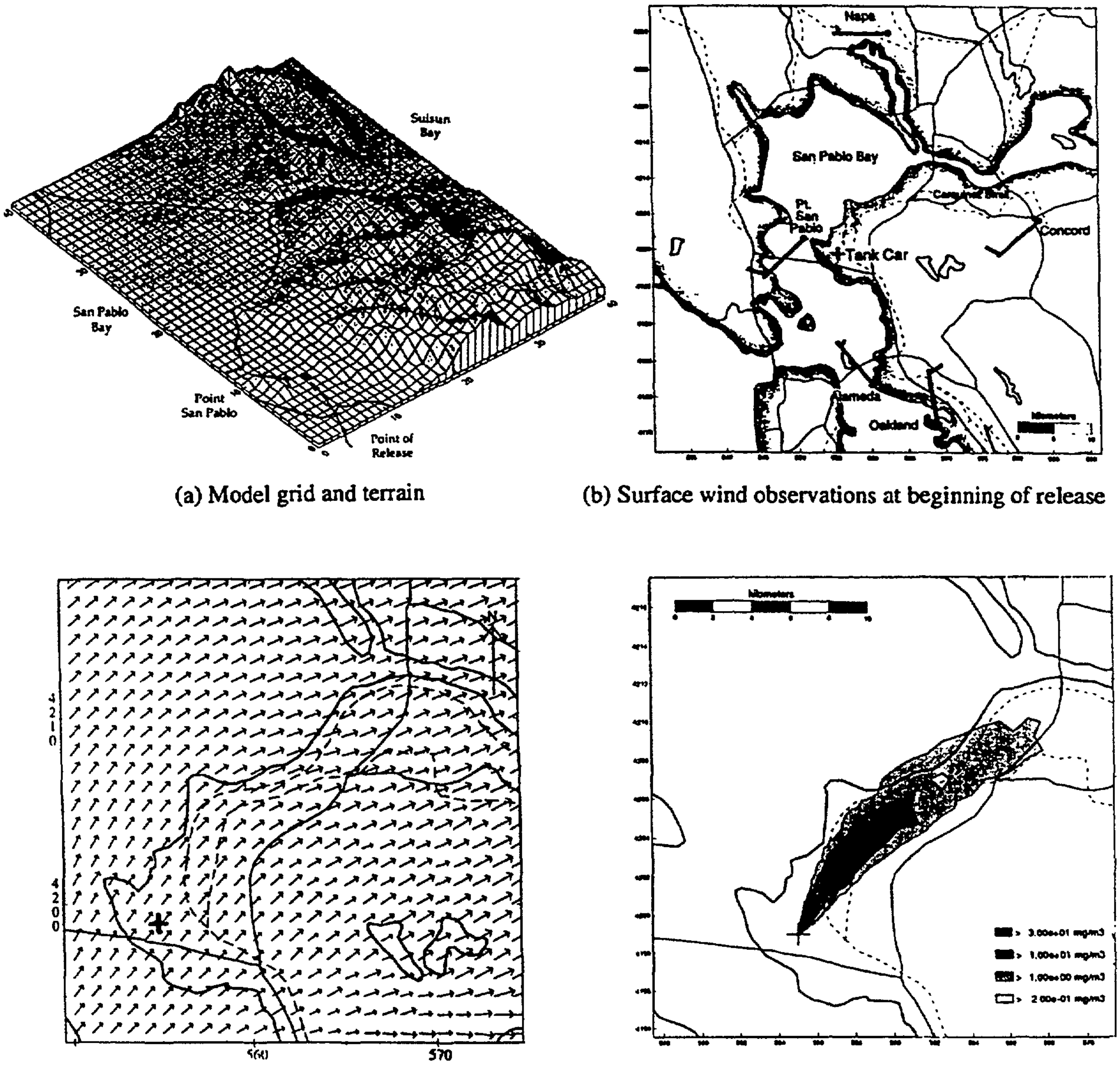
3. MODEL LIMITATIONS AND IMPROVEMENTS

ARAC has conducted over a dozen studies comparing the model calculations with tracer field measurements on the 10 to 100 km scale. Results show that the diagnostic codes compare to within a factor of 2 of the measurements about 20 to 50% of the time and to within a factor of 5 about 35 to 85% of the time depending on the complexity of the flow. Clearly there is room for improvement in model accuracy.

Accurately locating the plume is the most important goal of an emergency response model. The effect of turbulent spread is usually secondary except for light wind conditions or very near the source. For diagnostic models, thermally driven flows such as sea breezes, slope flows, or convective motion are not created in the calculation. Resolving these features relies primarily on the representation of input wind observations. For urban-scale diagnostic models the greatest single improvement can be accomplished with more representative meteorological observations (Lange 1984), especially vertical wind profiles (Baskett et al. 1990). Even if wind data exists at several urban airports, diagnostic models suffer from the lack of sufficient real-time observations to describe complex flow fields near an accidental release. This is especially true during stable nocturnal conditions such as the 1984 Bophal accident (Singh and Ghosh 1987).

The recent ARAC response to a large oleum tank car release in the San Francisco Bay Area of California (Baskett et al. 1994) demonstrates some limitations of diagnostic models in a complex setting. Early on the morning of July 26, 1993 in the city of Richmond, while a railroad tank car was being heated, a pressure relief valve failed. Over 7000 kg of sulphur trioxide gas was released to the atmosphere before the valve could be capped 3.75 hours later. The gas quickly condensed into a dense sulphuric acid mist which was observed to spread about 10 km downwind. Figure 2a shows the terrain setting and Figure 2b shows the surface wind observations available at the time of the release. The tank car was located between three airports (Napa, Concord and Alameda). Fortunately the local air quality management district operated a tower at Pt. San Pablo which was only about 5 km from the accident. Figure 2c shows the wind field and Figure 2d shows the plume location using the nearby tower. Without that tower's real-time data, the diagnostic wind model would have placed the plume 60 degrees more clockwise than occurred.

Furthermore, in a post-accident analysis, wind data from a refinery 1.5 km north of the release showed that more variable winds and more turbulence occurred at the accident than were observed at Pt. San Pablo. The Pt. San Pablo tower was influenced by flow over the Bay while the sulphuric acid plume experienced flow over a small ridge and an industrialised urban area. Allowing for a variable range of influence by individual observations is the next improvement planned with a new wind field generator, WINDGEN. In addition, the new model will use a terrain-following co-ordinate system to eliminate cell-face errors from block terrain. Future improvements will focus on detailed effects of spatially-varying mixing heights, land use, and surface roughness, including local features such as small hills, lake and ocean shorelines.



(a) Model grid and terrain

(b) Surface wind observations at beginning of release

(c) Surface wind field at beginning of release

(d) Second hour sulfuric acid air concentration

Figure 2. Example urban-scale dispersion model calculation for the July 26, 1993 Richmond, California toxic spill

Improvements are also planned to use spatially-varying precipitation measurements. As with wind data, the realism of the model is strongly tied to the ability of the measurements to resolve variations in the precipitation field, especially during convective (thunderstorm) conditions.

4. PROGNOSTIC MODELING

The advent of more powerful computers has created the opportunity to implement more sophisticated mesoscale prognostic models which will reduce the dependence on meteorological observations. Prognostic models require supercomputers to solve the primitive set of atmospheric equations and produce results faster than real-time. Mesoscale prognostic models are initialised by multi-layer gritted synoptic scale forecast models such as the U.S. National Weather Service Nested Grid Model (NGM). The NGM produces forecast datasets every 6 hours on a 90 km horizontal grid spacing. Features smaller than 90 km on a side are resolved by the mesoscale model. Mesoscale models include boundary layer dispersion physics driven by radioactive transfer, soil processes and the surface energy balance. In addition aerosol and cloud microphysics are parameterized to estimate localised cumulus convection, and aerosol and water mass budgets.

High-end workstations which compute forecasted wind fields up to 48 hours in the future are being used to run prognostic models continuously at a single location (Nappo et al. 1993, Yamada 1993, Tremback et al. 1994, Fast and O'Steen 1994). Operating prognostic models at an arbitrary location provides different challenges with different design considerations. To demonstrate the feasibility of using prognostic models for a national system, we successfully simulated the atmospheric flow field for the 1993 Richmond oleum spill. Next year we will begin implementing a mesoscale model for the ARAC system.

5. CONCLUSIONS

Determining the extent of contamination from computationally fast three-dimensional diagnostic models is the first step in responding to an accidental atmospheric release in or around a city. Improved physics which account for spatially-varying phenomena will increase model accuracy. These improvements will benefit from real-time access to more automated surface and upper air (sodar and wind profiler) meteorological systems, such as from air quality management districts and industry. After the initial diagnostic run, new prognostic models offer promise in simulating releases which extend more than a few hours and in locations with sparse meteorological observations.

ACKNOWLEDGEMENTS

This work was performed under the auspices of the Department of Energy by Lawrence Livermore National Laboratory under Contract W–7405–Eng–48 and by EG&G Energy Measurements, Inc. under Contract DE–AC08–93–NV11265.

REFERENCES

[1] BASKETT, R.L., NASSTROM, J.S., LANGE, R., The value of on-site sodars versus nearest radiosonde soundings in regional emergency response modelling, Pittsburgh, PA: Air & Waste Mgmt. Assoc. Proc. of the 83rd Annual Mtg. of the Air & Waste Mgmt. Assoc., Pittsburgh, PA., Paper 90–85.3 (1990).

[2] BASKETT, R.L., VOGT, P.J., SCHALK, W.W. III, POBANZ, B.M., ARAC dispersion modelling of the July 26, 1993 oleum tank car spill in Richmond, California, Livermore, CA: Lawrence Livermore National Laboratory Report UCRL–ID–116012 (1994) p.53.

[3] FAST, J.D., O'STEEN, B.L., Atmospheric and dispersion modelling in areas of highly complex terrain employing a four-dimensional data assimilation technique, Amer. Meteor. Soc. and Air & Waste Mgmt. Assoc., 8th Joint Conf. on Applications of Air Pollution Meteor, Nashville, TN., (1994) 309–315.

[4] LANGE, R., Relationship between model complexity and database quality for complex terrain tracer experiments, Amer. Meteor. Soc., 3rd Conf. on Mountain Meteor., Portland, OR, (1984) 17–21.

[5] NAPPO, C.J., ECKMAN, R.M., LUHAR, A.K., A high resolution transport and diffusion model for complex terrain environments, Chicago: Amer. Nuclear Soc. Proc. of the Topical Meet. on Environ. Transport & Dosimetry, Charleston, SC (1993) 89–92.

[6] TREMBACK, C.J., LYONS, W.A., THORSON, W.P., WALKO, R.L., An emergency response and local weather forecasting software system, Amer. Meteor. Soc. and Air & Waste Mgmt. Assoc., 8th Joint Conf. on Applications of Air Poll. Meteor, Nashville, TN (1994) 219–223.

[7] SINGH, M.P., GHOSH, S., Bhopal gas tragedy: Model simulation of the dispersion scenario, J. Hazard. Materials **17** (1987) 1–22.

[8] SULLIVAN, T.S., ELLIS, J.S., FOSTER, C.S., FOSTER, K.T., BASKETT, R.L., NASSTROM, J.S., SCHALK, W.W. III., Atmospheric Release Advisory Capability: Real-time modelling of airborne hazardous materials, Bull. Amer. Meteor. Soc. **74** (1993) 2343–2361.

[9] YAMADA, T., Application of three-dimensional numerical models to emergency response management, Pittsburgh, PA: Air & Waste Mgmt. Assoc. Proc. of the 86th Annual Mtg. of the Air & Waste Mgmt. Assoc., Paper 93–FA–168.04 (1993).

DECISION ANALYSIS FOR CLEANUP STRATEGIES IN AN URBAN ENVIRONMENT

XA0054899

K. SINKKO, T.K. IKÄHEIMONEN
Finnish Centre for Radiation and Nuclear Safety,
Helsinki, Finland

Abstract

DECISION ANALYSIS FOR CLEANUP STRATEGIES IN AN URBAN ENVIRONMENT.

The values entering the decisions on protective actions, as concerning the society, are multidimensional. People have strong feelings and beliefs about these values, some of which are not numerically quantified and do not exist in monetary form. The decision analysis is applied in planning the recovery operations to clean up an urban environment in the event of a hypothetical nuclear power plant accident assisting in rendering explicit and apparent all factors involved and evaluating their relative importance.

1. INTRODUCTION

A comprehensive overview of the important methods to clean up large areas contaminated as a result of a nuclear accident is available in the literature (IAEA, Le, Ro). The successful implementation of actions, however, requires good planning including the identification of multidimensional values entering the decision. These values, expressed as objectives, criteria or performance measures, will necessarily be a part of the final decision making following radiological emergencies. The aim of the identification of values and the assessment of their relative importance on decisions is to create better alternatives for decisions and to define decision problems that are more appealing than those that confront us.

Research over the past 30 years has transformed the abstract mathematical discipline of decision theory to a potentially useful technology known as *decision analysis*, which can assist decision makers in handling large and complex problems and the attendant flows of information (Fr, Go, Wi). Decision analysis is not intended to solve problems directly. Its purpose is to produce insight and understanding, so that the decision maker can make better decisions. This report provides an application on how techniques of decision analysis can be used when planning cleanup measures in urban environment.

2. DECISION MODEL

For the purpose of the analysis it was assumed that a hypothetical core-damaging accident had happened at a Finnish nuclear power plant and, as a result, a few percent of the fission products had been released to the environment. It was further assumed that the accident had happened in summer time in dry atmospheric conditions. The contamination levels and the areas were evaluated with the OIVA software package (Fig. 1, La). The range of values corresponds the deposition onto infinite grass surface where all the deposited matter is on the grass cover. The mean values were estimated taking into account typical differences in deposition on various urban surfaces.

The distribution of the deposited material onto different surfaces and the contribution that each surface has to the dose was considered in developing decontamination strategies. The most cost-effective techniques given in the literature to decontaminate each surface were then selected to achieve effective dose reduction (Le, Ro). In addition, the postponement of the cleanup and the width of the area to be cleaned up will affect the net benefit to be obtained.

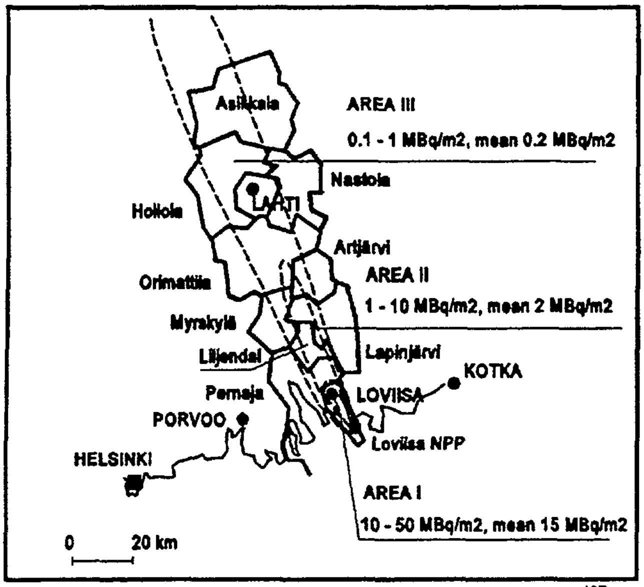


Figure 1. The map showing the distribution of the ^{137}Cs contamination after a hypothetical reactor accident. The mean values are relevant in urban environment.

The effect of the width of the area is studied with moderate and extensive decontamination alternatives. In extensive decontamination the area was chosen to be twice as large as that of moderate decontamination. To form the policy of the protection seven strategies were defined (Table I).

TABLE I. STRATEGIES FOR RECOVERY OPERATIONS IN URBAN AREAS DEFINED IN TERMS OF THEIR EFFECTS ON THE AREAS I, II AND III.

Strategy	Firehosing of roofs	Firehosing of walls	Sweeping of streets	Cutting trees	Grass cutting	Scraping/ clean soil	No action
1	I, II, III	I, II, III	I, II, III	I, II, III		I, II, III	
2	I, II, III	I, II	I, II, III	I, II	III	I, II, *III*[a]	
3	I, II	I	I, II	I	II	I, *II*[a]	III
4[b]	I, II	I	I, II	I	II	I, *II*[a]	III
5			I, II, III		I, II, III		
6	I		I		I	*I*[a]	II, III
7							I, II, III

a) Only the nearest surroundings of the houses are scraped
b) Decontamination is started one month after the fallout.

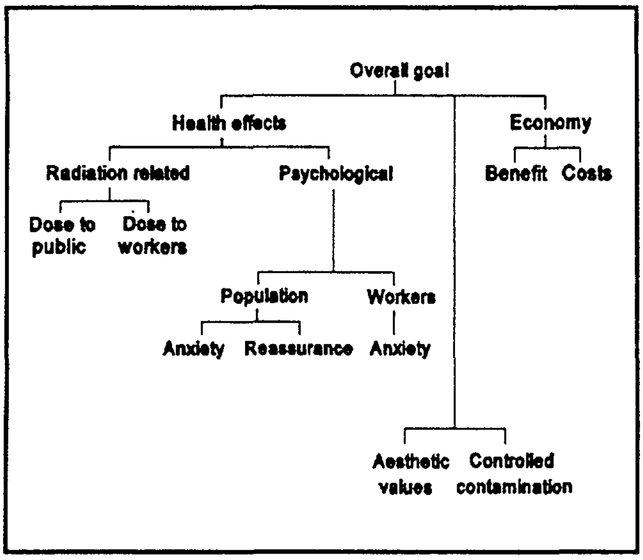


Figure 2. Hierarchy of attributes used in the decision model.

Although we have defined alternatives above, it is useful to iterate between articulating values and creating alternatives. *Alternatives are relevant only because they are means to achieve values.* Since environmental values are multidimensional, different kinds of objectives will necessarily be involved in any decision following radiological emergencies. Some of the objectives might be directly measured on a numerical scale and some should be further divided into sub-objectives in order to be measurable. This kind of a numeric variable is called an attribute, and it is used to measure performance of actions in relation to an objective. An *attribute hierarchy* (*value tree*) can be useful in defining attributes and objectives (Fig. 2). The attributes used in the analysis are defined as follows:

Dose to the public. Because the dose of the population is not known on an individual basis, the value of this attribute is assessed as the projected (residual) collective dose to the public (manSv).

Dose to the workers. Projected collective dose to the workers carrying out the recovery operations (manSv).

Anxiety of the population. Psychological stress could lead to health effects of a comparable nature to those arising from the contamination. A majority of the population in a contaminated area may show varying degrees of stress reactions in response to an accident, but stress could also be the consequence of a protective action. The accident will be realized through protective measures and it will be felt more severe if numerous and aggressive measures are taken, e.g., removing soil and trees in living environment (direct rating).

Reassurance of the population. In the long term, appropriate and reasonably extensive actions will offer reassurance to the population to live safe in the affected area. Especially measures that the population could implement by itself are the most effective in reducing stress (direct rating).

Anxiety of the workers. Working in the contaminated area will cause stress among workers when intervening (direct rating).

Aesthetic values. Decontamination methods such as digging, scraping and especially felling down trees would result in the reduction of contamination, but at the same time, decrease the aesthetic value of the environment. The reduction would also take place near disposal sites and around power stations burning radioactive wood (direct rating).

Controlled contamination. The contamination is brought under control and its circulation in the environment is prevented by collecting and disposing it (direct rating).

Costs. Cleanup would cause monetary costs to individuals, industry and society. The question of reimbursing individuals for any remedial actions would also arise. If any compensation is paid, either in full or in part, it would mean that the costs to individuals would now be costs to society. The costs that are taken into account include the costs of the removal of contamination, transportation and disposal of waste (MFIM).

Economic benefit. The economic impact of an accident may not be entirely negative. The activities may have positive effect on the economy, such as manufacturing and trading decontamination equipment and generation of employment. Unfortunately no models exist that would enable the consideration of full economic activities and therefore the assessment of benefit was based on expert assessment (Ni) and on the calculated benefit of burning the chipped wood. (MFIM).

The measurement of the quantifiable attributes is easy, because we can identify the variables representing them. However, for attributes, such as reassurance and aesthetic values, it is more difficult to find proxy attributes or variables that can be quantified. *Direct rating* can be used with unquantifiable attributes. In this technique, the most preferred option for, e.g., reassurance, is given a value of 100 and the least preferred option the value of zero. The other options are ranked between zero and 100, according to the strength of preference for one option over another in terms of reassurance. Although this technique seems robust, it should be emphasized that there are methods of checking the consistency of the numbers elicited. Also, numbers do not need to be precise. The choice of action is generally fairly robust and substantial changes in the figures are often required before another option is preferred. The assessed values of attributes for each strategy are given in Table II (1 USD = 5 FIM).

TABLE II. VALUES OF THE ATTRIBUTES FOR STRATEGIES DEFINED IN TABLE I

Strategy	Dose to public (manSv)	Dose to workers (manSv)	Benefit (MFIM)	Costs (MFIM)	Anxiety of population (score)	Reassu-rance (score)	Anxiety of workers (score)	Aesthetic values (score)	Controlled contamin. (score)
1[a]	1180	15	140	690	0	90	0	0	100
2[a]	1340	10	30	120	10	100	50	70	80
3[a]	1700	8	10	60	50	50	70	90	30
3[b]	1360	16	17	110	40	60	60	80	50
4[a,c]	1810	2	10	60	30	40	80	80	40
5[b]	1430	1.8	1.8	3.7	60	40	60	100	60
6[b]	1870	1.1	1.5	3.4	80	30	90	100	20
7	2670	0	0	0	100	0	100	100	0

a) Moderate decontamination
b) Extensive decontamination
c) Decontamination is started one month after the fallout.

The reduction in the dose through cleanup is assessed based on calculations done by Andersson and Roed with the URGENT software package (Le) and on real statistics obtained in the defined fallout areas. The dose predictions for over 70 years were done by the ARANO software package (Sa). The dose to each worker group in each work phase was calculated separately; firehosing of roofs and walls, sweeping of streets, removal of vegetation and soil, transportation and disposal of waste. The software package MATERIA was used to assess the individual doses to workers during transportation and disposal (Ma). The monetary costs of actions were calculated using Finnish statistics and information collected in another study (Le). The scales for unquantifiable attributes were developed judgementally. A higher score represents more preferred actions.

Before we can combine the values for different attributes in order to obtain a view of the overall benefits offered by each strategy, we have to assess the weights on attributes. They represent the judgement of the decision maker on the relative importance of the levels of attributes. For example, how much he/she is ready to accept dose to workers to avoid a certain dose to the population. When assessing a trade-off value, it should be noted that the importance of an attribute is not only dependent on its conceptual value, such as health, but also on its *length of scale*, such as the number of cancer cases. *Swing weighting* is applied in the analysis as an assessment method for scaling constants. The decision maker is asked to compare a set of pairs of hypothetical actions which differ only in their values along two attribute scales until an indifferent pair of options is found. Based on the swing weighting assessments the following weights are obtained (Table III).

TABLE III. WEIGHTS OF ATTRIBUTES

Attribute	Costs	Dose to public	Benefit	control. contam	Reassu-rance	Aesthetic values	Anxiety of popul.	Anxiety of work.	Dose to workers
Weight	56	13	11	8	5.6	4	2.8	0.28	0.1

3. ANALYSIS OF THE MODEL

At this stage we are in a position to aggregate the values to find out how well each strategy performs overall. The *additive model* was applied simply to add together the weighted value scores of an action (weighted attribute values on each strategy) to obtain the benefit. Additive model, although robust, was considered here to be useful to gain an understanding of values. The overall scores and ranking of strategies are given in Table IV. Strategy 5^b, sweeping of streets and grass cutting extensively in the whole contaminated area is just optimal.

TABLE IV. OVERALL SCORES FOR THE ANALYSIS

Strategy	1^a	2^a	3^a	3^b	$4^{a,c}$	5^b	6^b	7
Overall score	0.37	0.74	0.70	0.71	0.68	0.79	0.72	0.63
Rank	8th	2nd	5th	4th	6th	1st	3rd	7th

a) Moderate decontamination
b) Extensive decontamination
c) Decontamination is started one month after the fallout.

It is wise to be sceptical about the ranking of the actions, if the variation of figures used in the analysis is not analysed by means of a sensitivity analysis. We have to examine the robustness of the choice of a strategy in the light of changes in the figures. In many cases sensitivity analysis shows that the data need not to be accurate. If this is the case, then it would be a waste of effort and time to elicit the numbers accurately. There are several techniques described in the literature for performing a sensitivity analysis. The most straightforward analysis, applied here, examines the effects of varying one parameter at a time.

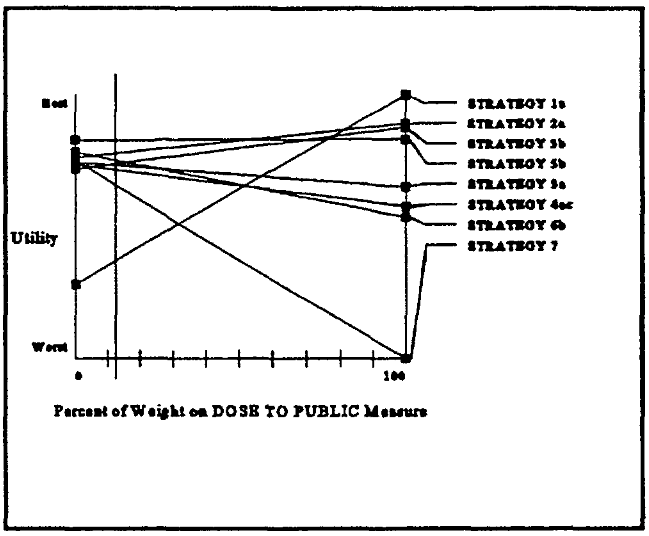


Figure 3. Sensitivity analysis on collective dose.

As an example of the sensitivity analysis performed is the analysis on the weight of collective dose (Fig. 3). The weight on dose is about 13% of the total weight in the model and this value is marked with the vertical line in the Figure 3. The overall score for each strategy against the percentage of total weight on dose are plotted with a line. The highest line segments gives the maximum utility, and hence the line with the highest intersection with the vertical line shows the optimal strategy, i.e., strategy 5^b; sweeping streets and grass cutting in the whole area.

As the weight on dose is below 50% strategy 5^b is optimal, but above 50% strategy 2^a and then strategy 1^a (80%) will be the best course of action, respectively. Besides the range (0 – 50%) gives the accuracy needed in weighting the dose attribute, it also reflects the required accuracy in the dose calculation because the 'length' of an attribute scale is taken into account when assessing the trade-off. The accuracy in assessing the trade-off between collective dose and costs attributes was also studied by changing the trade-off value, increasing the '-value' in radiation protection terminology from 100,000 FIM/manSv to 300,000 FIM/manSv. At this breakeven point strategy 2^a is optimal.

The analysis suggests that the best course of action is strategy 5^b. There should be modifications done in strategy 2^a or changes in numbers or trade-offs before this action will become more attractive. As is shown in Figure 3 strategies 3, 4, 6 and 7 can never be optimal considering the values and the trade-offs used in the analysis.

4. CONCLUSIONS

The decision analysis performed suggests that grass cutting and sweeping of streets would be the best course of action to be taken in the analysed situation. The extensive decontamination, e.g., cutting down trees and removal of soil is not appropriate considering the contamination level and the large area to be cleaned up. Although the less quantifiable factors appeared to be less important in an analysed situation considering the values and trade-offs used, they certainly have a valuable role to play in gaining insight in decision making.

There are different preferences connected to the values of attributes. Therefore, *the values of attributes and trade-offs are subjective*, not objective. Expressing the value may be both unpleasant and difficult, but often it is very crucial when assessing an intervention level. Since the values are subjective, no universal values exist. The values are related to the unique problem, and in addition, they change according to opinions and resources. Careful structuring of the problem is necessary to identify the underlying multidimensional values, attitudes to risk and trade-offs related to the problem. To create more insight, more research is needed, specially on the less quantifiable factors.

The analysis represented above is based on a hypothetical accident. In a real problem, depending on prevailing circumstances, more strategies would have to be considered. Also, the factors entering the decision depend on the situation. Thus, the results of the performed analysis could not be applied in a real situation as such, but the actions and factors should be revised and the calculations redone. The strategies found appropriate in the analysed situation might turn out not to be the most preferred for the real problem, however, they might well indicate the course of actions to be considered.

ACKNOWLEDGMENTS

We are grateful to MA Liisa Eränen, Dr. Raimo Mustonen, Dr. Anneli Salo and Dr. Tapio Rytömaa for taking part in the analysis and giving their judgements and advice.

REFERENCES

[1] FRENCH, S., Decision theory: an introduction to the mathematics of rationality, Ellis Horwood, Chichester (1988).

[2] GOODWIN, P., WRIGHT, G., Decision analysis for management judgement, John Wiley & Sons, Chichester (1992).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Cleanup of large areas contaminated as a result of a nuclear accident, Technical reports series No.300, IAEA, Vienna (1989).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Planning for cleanup of large areas contaminated as a result of a nuclear accident, Technical reports series No. 327, IAEA, Vienna (1991).

[5] LAHTINEN, L., BLOMQVIST, L., OIVA-on off-site dose prediction system using real-time plume trajectories, Report EUR 12320, CEC, Luxembourg (1990).

[6] LEHTO, J., Cleanup of large radioactive-contaminated areas and disposal of generated waste, NKS KAN2 project, (in press) (1994).

[7] MARKKANEN, M., Personal communication, Finnish Centre for Radiation and Nuclear Safety (1993).

[8] NIEMI, E., Personal communication, Statistics Finland (1994).

[9] ROED, J., Deposition and removal of radioactive substances in an urban area, NKA project AKTU-245, Malmö (1990).

[10] SAVOLAINEN, I., VUORI, S., Assessments of risks of accidents and normal operation at nuclear power plants, Technical Research Centre of Finland, Nuclear Engineering Laboratory, Electrical and Nuclear Technology Publication **21** (1977).

[11] VON WINTERFELDT, D., EDWARDS, W., Decision analysis and behavioral research, Cambridge University Press (1986).

XA0054900

RADIOACTIVE CONTAMINATION OF AN URBAN ENVIRONMENT UNDER WINTER CONDITIONS

U. TVETEN
Institutt for energiteknikk,
Kjeller, Norway

Abstract

RADIOACTIVE CONTAMINATION OF AN URBAN ENVIRONMENT UNDER WINTER CONDITIONS.

A considerable number of nuclear installations are geographically positioned in areas where there are winter conditions part of the year. Nevertheless accident consequence analyses are almost without exception carried out assuming that there is always summer conditions. The reason for this may be that the consequences will usually be more several during summer conditions than during winter conditions, at least when agricultural production is considered. In an urban area, however, it is not self-evident that this will be the case. Furthermore, the decisions to be taken in an emergency situation may differ with the season.

Some relevant experiments were carried out as part of the safety program sponsored by the Nordic Liaison Committee for Atomic Energy and was partially funded by the Nordic Council of Ministers.

In the present paper these experiments, concerning run-off from roofs of buildings and decontamination during winter conditions, are described, and various other aspects of winter conditions of potential importance to accident consequences and decision making during winter conditions are discussed.

1. INTRODUCTION

A considerable number of nuclear installations are geographically positioned in areas where there is winter conditions a significant portion of the year. These are not only installations in Scandinavia, but also in e.g. Canada, the Northern United States and in Russia. Nevertheless accident consequence analyses are always carried out assuming summer conditions.

Knowledge of the winter behaviour of radioactive materials is unfortunately very limited. Some knowledge was gathered during the 1950's and 1960's in connection with weapons fall-out, but this is mainly for rural areas. Some measurements performed in connection with investigations of acid precipitation are relevant, but these are also for rural areas. When fall-out from the Chernobyl accident reached Northern Scandinavia in April/May 1986 there was still winter conditions in some of the mountain areas, but there were other aspects that were more important in the acute phase.

A recent literature search has brought up little new information of relevance. Some experiments were carried out at our Institute during the 1980's, as part of the Nordic Safety Program, sponsored by the Nordic Liaison Committee for Atomic Energy and partially funded by the Nordic Council of Ministers. Although the first of these experiments was carried out more than ten years ago, they are still relevant and unique.

2. WINTER CONDITIONS

The possible consequences of a reactor accident under winter and summer conditions will differ for a number of reasons:

• *Deposition on snow and with snow*

A snow-covered surface will normally be much smoother than the same surface covered with grass, and dry deposition will accordingly be less under winter conditions. This is observed in (GR83 and PA88).

"Wet" deposition during snow-fall will be larger than deposition with rain, since the snow-flakes have very large surfaces relative to the amount of water contained. Here there are many relevant references: (EN66, WO69, GR75, KN76, KN77, SL84, Kü85 and SP93).

Another important difference between deposition with rain and deposition with snow, not addressed in these references, is that when materials deposit with strong rainfall, the immediate run-off may be considerable. When materials deposit with snow, there is no run-off until the next melting period.

Furthermore, since the wind may often create snow-drifts, there is also the possibility of local hot spots in the places where snow accumulates. Both this effect and the one in the previous paragraph may give higher local ground concentrations in the winter case, particularly in urban areas.

• *Weathering during winter and throughout spring will be different from that during summer conditions both in urban and rural areas*

A number of different measurements indicate that contaminants (including radioactive materials) move only insignificantly during stable freezing conditions, but when melting conditions occur, the contaminants will move rapidly with the first melt water. This may even take place at temperatures below zero degrees Centigrade, since the presence of contaminants may lower the melting point.

Materials in solution will be carried away with the melt water. Caesium, however, may become attached to materials at the bottom of the snow layer (soil, asphalt), depending upon the conditions, and stay more or less in the place where it was deposited. If there is a sufficiently thick ice layer at the bottom of the snow layer, contact between caesium and soil or asphalt may not take place, and the radioactivity is removed from the area to a larger degree. This situation illustrates the importance of the weather conditions at a time perhaps long before contamination took place. The snow and ice conditions are a function of the weather over a whole winter season. Normally a winter starts with a series of alternating freezing and melting periods. An ice layer is formed if melting is only partial before the next freezing period occurs. In late winter the sun may melt the top layer of the snow during the day. During night this layer will melt and form a crust. Even if new snow falls on top of this crust, the crust layer will stay inside the snow layer, and may stop the downward movement of contaminants during subsequent melting periods, lead to horizontal displacement of contaminants, and may also prevent contact between e.g. caesium and soil or asphalt.

• *Decontamination may be much cheaper and much less destructive under winter than under summer conditions*

If decontamination is performed before the next melting period occurs, contaminants that have been deposited on snow will remain in the snow layer and can be removed together with the snow. This situation has been examined in a few experiments performed in Norway and described in more detail later in this paper.

• *Snow provides additional shielding against ground shine*

Snow provides shielding against radioactive materials under the snow. The shielding effect of snow against natural radiation sources in the ground was examined in (FU88).

It was found that it reduced indoor exposure by 20–30%. This result is, however, not directly applicable to other areas or situations.

3. RELEVANT EXPERIMENTS

A recent literature search revealed little new information in addition to the already mentioned experiments carried out at our Institute (QV84a, QV84b, QV86).

However, behaviour of the nuclides Sr-90 and Cs-137 from weapons fall-out under winter conditions was studied in the late 50s at the Norwegian Defence Research Establishment. Some relevant references are (BE59 and LU62). An important observation made is that the deposited materials in the different layers of snow were relatively stable as long as no melting of snow occurred, but as soon as melting or rain happened, the activity was rapidly washed down through the snow, increasing the concentrations in the bottom layers. The rapid migration of impurities in snow under melting conditions can be explained as follows: When deposition takes place in cold weather, the impurities will deposit on the surface of the snow crystals. When melting starts, the outer layers of the crystals will melt first, and the impurities follow this water down through the layers of snow. The melting process is found to sometimes take place even if the air temperature is below the freezing point, and it is reasonable to assume that the presence of the impurities has caused a local lowering of the melting point.

Aspects of winter conditions have also been investigated in the Norwegian Interdisciplinary Research Program: Acid Precipitation — Effects on Forest and Fish), (DA78, DA79, DA80, JO78, OV80 and SE80). An experiment was performed in which a colour compound was sprayed on snow. By cutting out vertical samples, migration of the colour in the snow could be followed. The conclusions are like those in the previous paragraph. Horizontal migration was also found, as the colour could migrate sideways several meters along the horizontal layers of icy snow in the snowpack.

3.1. Weathering from roofs under winter conditions

An investigation of natural decontamination (weathering) of roof materials was performed at the Institutt for energiteknikk, Norway in 1982 - 84 during summer and winter conditions. The "roofs" used in the experiments consisted of a supporting wooden structure with a plywood board (1.2 x 2.4 meters) on top. There were several roofs, some covered with ordinary tar-paper and some with a steel roof material, both typical of modern houses in Norway. Only the tar-paper roofs were used in experiments relevant to winter conditions. The run-off water was collected in a plastic gutter, and collected in a container. The radioactive material used in the experiments was Cs-134 (as chloride), applied in stripes across the roof, using a small spray bottle.

The "summer" experiment was started on the 29 October 1982. There was still no snow or frost. After 2 days and a precipitation of 7 mm the remaining activity on the tar-paper roof was 97%. When the measurements were terminated (about 8 months after contamination) 61% remained on the roof after a total of 589 mm precipitation.

The first "winter" experiment was performed in late March 1983. At the time of contamination the roof was covered with 8 cm of wet snow. After 3 days and the equivalent of 13 mm precipitation, 90% of the Cs-134 remained on the roof. After 3 months and 191 mm precipitation the remaining activity on the roof was 59%.

An experiment on a roof with stable snow- and ice-cover was carried out in winter 1984. When the caesium was applied there was a stable layer of ice and coarse-grained snow on the roof, approximately 5 cm thick, and there was light snow-fall. During the time needed to add the activity, roughly 1 cm of additional snow accumulated, increasing to another 5 cm during the following night. The temperature when the activity was added was -7^{0}C. 9 days later came the first day with run-off, after which 84% of the added activity remained on the roof. After 15 days, when all snow had disappeared from the roof, 53% of the activity remained; and when the experiment was terminated, after 4 months and 141 mm of precipitation, 35% remained.

The experiments show that run-off, both short-term and somewhat more long-term, is significantly more rapid during winter than during summer conditions. Such experiments ought to be performed for a larger variety of combinations of weather conditions, for different roof materials and for materials representative of other surfaces of importance in a contamination situation. A weakness of these experiments is that they were not performed on real houses. A house will be a heat source, and this may have impact upon the run-off.

3.2. Decontamination during winter

The experiments on decontamination were performed several years apart (1984 and 1988). The first experiment is reported in (QV84b). The second experiment has not been reported separately, but is reported, together with a number of other projects within the Nordic Safety Program in (TV90).

Post-Chernobyl experience in Norway was that the major contributions to the dose are via nutrition (not relevant in urban areas) and exposure to radiation from radioactive materials deposited on ground and other surfaces. Accordingly, one of the ways in which doses resulting from an accident can be reduced is by decontamination. Decontamination under summer conditions is both costly and destructive. If contamination takes place during winter, decontamination may be both simpler and cheaper.

The winter decontamination experiments performed at our Institute were performed using standard, though rather small-scale, snow-removal equipment. It would have been interesting to carry out experiments using the much larger machines ordinarily used on roads, but this could not be managed with the modest funds available. A non-radioactive contaminant (coppersulphate) was used in the experiments.

The first decontamination experiment was carried out 21 March 1984. A small parking lot of ca. 30 m^2 at our Institute was used. On the asphalt was a layer of solid ice of thickness 1 to 7 cm, covered with ca. 5 cm of undisturbed snow. A portable mist spray unit (ordinarily used for spraying pesticide) was used to contaminate the area. The air temperature was -3^{0}C when contamination was carried out. Then the snow was removed from the area, using a tractor with a shovel. More than 99% of the contaminant was removed.

Two further winter decontamination experiments were carried out in March 1988: In one case on a road where there was only a quite thin layer of ice and hard-packed snow, and in the other case on relatively compact snow topped by a layer of new-fallen snow a few centimetres thick (typical of a situation on side-walks in towns). On the road roughly 25% was removed, on the "side-walk" roughly 99.5%.

4. GENERAL CONCLUSIONS AND REMARKS

The few "winter" experiments carried out as part of the Nordic Safety Program indicate that run-off is significantly larger under winter conditions, and that the decontamination efficiency during winter conditions may be very high and the cost very low.

The investigations at our Institute were discontinued, and we have not yet found a sponsor for further work in this field. To our knowledge similar experiments have not been carried out elsewhere.

REFERENCES

[1] BERG, H., FINSTAD, G., LUND, L., MICHELSEN, O., OTTAR, B., BE59, Radiochemical analysis of precipitation, tap water and milk in Norway 1957, 1958, Norwegian Defence Research Establishment, FFIK Internal Report K-219, Reference: 32.4-K/117:173, Norway (1959).

[2] DAHL, J.B., QVENILD, C., TOLLAN, O., CHRISTENSEN, N., SEIP, H.M., DA78, Methodology of studies of chemical processes in water run-off from rock and shallow soil using radioactive tracers, Water Air Soil Poll. II, p. 179-190. Also SNSF Project. TN42/78. Norway (1978).

[3] DAHL, J.B., SEIP, H.M., TOLLAN, O., DA79, Chemical processes involving calcium and sulphate in water run-off from rock and shallow soil studied using radioactive tracers, (in Norwegian). SNSF Project, IR49/79, Norway (1979).

[4] DAHL, J.B., QVENILD, C., TOLLAN, O., CHRISTENSEN, N., SEIP, H.M., DA80, Use of radioactive tracers to study run-off and soil-water interactions in natural mini-catchments, (DRABLØS D., TOLLAN, O., Eds.): Ecological impact of acid precipitation, p. 160–161. SNSF Project. Norway (1980).

[5] ENGELMANN, R.J., PERKINS, R.W., HAGEN, D.I., HALLER, W.A., EN66, Washout coefficients for selected gases and particulates, BNWL-SA-657, USA (1966).

[6] FUJIMOTO KENZO, KOBAYASHI SADAYOSHI, FU88, Shielding effect of snow cover on indoor exposure due to terrestrial gamma radiation, International Congress of the International Radiation Protection Association, Pergamon Press, Vol. 3, Sidney, Australia (1988) 910–913.

[7] GRANAT, L., JOHANSSON, C., GR83, Dry deposition of SO_2 and NO_x in winter. Atmospheric Environment, Vol. 17, No. 1, Pergamon Press, Great Britain (1983) 191–192.

[8] JOHANNESSEN, M., HENRIKSEN, A., JO78, Chemistry of snow melt-water: Changes in concentration during melting, Water Res. Research 14 (1978) 615–619.

[9] GRAEDEL, T.E., FRANEY, J.P., GR75, Field measurements of submicron aerosol washout by snow, Geoph. Res. Lett. 2, No. 8 (1975) 325 pp.

[10] KNUTSON, E.O., SOOD, S.K., STOCKHAM, J.D., KN76, Atmospheric Environment, Vol. 10, Pergamon Press, Oxford (1976) 395–402.

[11] KNUTSON, E.O., STOCKHAM, J.D., KN77, Aerosol scavenging by snow: Comparisons of single-flake and entire-snowfall results, Precipitation Scavenging CONF–741003.

[12] KÜHN, W., BUNNENBERG, C., WEISS W., KÜ85, Washout of pollutants in the atmosphere by snow, (in German), Atomkernenergie. Kerntechnik, Vol. 47, No. 2, Germany (1985) 126–127.

[13] LUND, L., MICHELSEN, O., OTTAR, B., WIK, T., LU62, A study of Sr-90 and Cs-137 in Norway 1957-1959, Norwegian Defence Research Establishment FFIK Internal Report K-253, Reference: 32–K/136:173, Norway (1962).

[14] PARVEEN, N., SCHÜTTELKOPF, H., PA88, Pb-210 in ground-level air and snow in the environment of the Karlsruhe Nuclear Research Center, KfK 4345, Karlsruhe, Germany, January (1988).

[15] OVERREIN, L.N., SEIP, H.M., TOLLAN, O., OV80, Acid precipitation — Effects on forest and fish, Final report of the SNSF Project 1972–1980, Research Report FR19/80, Norway (1980).

[16] QVENILD, C., TVETEN, U., QV84a, Adsorption of Cs-134 onto two different types of roof materials during summer and winter conditions, IFE/KR/E–84/013, Kjeller, Norway, December (1984).

[17] QVENILD, C., TVETEN, U., QV84b, Decontamination and winter conditions, IFE/KR/E-84/014, Kjeller, Norway, December (1984).

[18] QVENILD, C., TVETEN, U., QV86, Run-off of strontium with melting snow in spring, IFE/KR/E-86/003, Kjeller, Norway, September (1986).

[19] SEIP, H.M., ANDERSEN, S., HALSVIK, B., SE80, Snowmelt studied in a mini-catchment with neutralised snow, SNSF Project IR65/80, Norway (1980).

[20] SLINN, W.G.N., SL84, Precipitation scavenging, RLO–2227–T27–2, Published in (RANDERSON, D., Ed.): Atmospheric science and power production, DOE/TIC–27601, USA (1984) 466–524.

[21] SPARMACHER, H., FÜLBER, K., BONKA, H,: SP93, Below-cloud scavenging of aerosol particle-bound radionuclides — experimental, Atmospheric Environment, Vol. 27A, No. 4, Pergamon Press (1993) 605–618.

[22] TVETEN, U., (Ed.), TV90, Environmental consequences of releases from nuclear accidents — A Nordic perspective, NORD 1990:46, Nordic Liaison Committee for Atomic Energy, Norway, March (1990).

[23] WOLF, M.A., DANA, M.T, WO69, Experimental studies in precipitation scavenging, PNL Annual Report 1968 to USAEC DBER, Vol. II, Pt. 1, Richland, USA (1969) 18–25.

XA0054901

DEVELOPMENTS IN EMERGENCY PLANNING WITHIN SCOTTISH NUCLEAR

A. SIMPSON
Emergency Planning,
Scottish Nuclear Ltd,
Glasgow, United Kingdom

Abstract

DEVELOPMENTS IN EMERGENCY PLANNING WITHIN SCOTTISH NUCLEAR.

Scottish Nuclear has recently completed a major program of improvements to its nuclear emergency facilities. The improvements include the construction of a purpose built Off-Site Emergency Centre for each of its two power stations and the development of a computer based information management system to facilitate the rapid distribution of information on an emergency to local, regional and national agencies. A computer code has also been developed to allow the rapid assessment of the effects of any accidental release on the local population. The improvements to the emergency facilities have been coupled with changes in local and national arrangements for dealing with a civil nuclear emergency.

The use of airborne surveying techniques for rapidly determining levels of deposited activity following an accident is also being examined and preliminary airborne surveys have been carried out.

1. INTRODUCTION

Scottish Nuclear Limited (SNL) was created in 1989 to take over the operation of the nuclear power stations in Scotland which were previously the responsibility of the South of Scotland Electricity Board. The Company owns and operates two Advanced Gas Cooled Reactor stations with a total capacity of 2.6GW(e) and supplies 50% of the Scottish electricity demand.

Scottish Nuclear is also responsible for the decommissioning of an earlier Magnox station on an adjacent site and is currently seeking permission to build dry stores for the long term site storage of irradiated fuel.

Following the creation of the company a review of the arrangements for dealing with an emergency was carried out and three key areas for improvement were identified:

Co-ordination of the multi-agency response
The distribution of information
Post accident radiological surveys

2. CO-ORDINATION OF THE MULTI-AGENCY RESPONSE

In the UK the operator of a nuclear site must have a license issued by the Nuclear Installations Inspectorate. The licence requires the operator, in conjunction with local emergency services and authorities to prepare an Emergency Plan detailing the response to any reasonably foreseeable accident.

A key feature in the Emergency Plan is the setting up of an Off-Site Centre (OSC) to co-ordinate the response of the emergency services and to provide an authoritative source of information to the public and media.

Scottish Nuclear decided that the previous arrangement of using converted office accommodation for the OSC was unsuitable for long term operations and imposed limitations on internal communications and layout that could not easily be overcome. It was therefore decided to construct purpose built OSCs for each of its sites.

The final design of the OSC was reached after consultation with the various emergency agencies involved and incorporates a central open plan 'Atrium Area', where representatives of local and national agencies are located and separate rooms for specialist functions, such as communications and directing radiological survey teams.

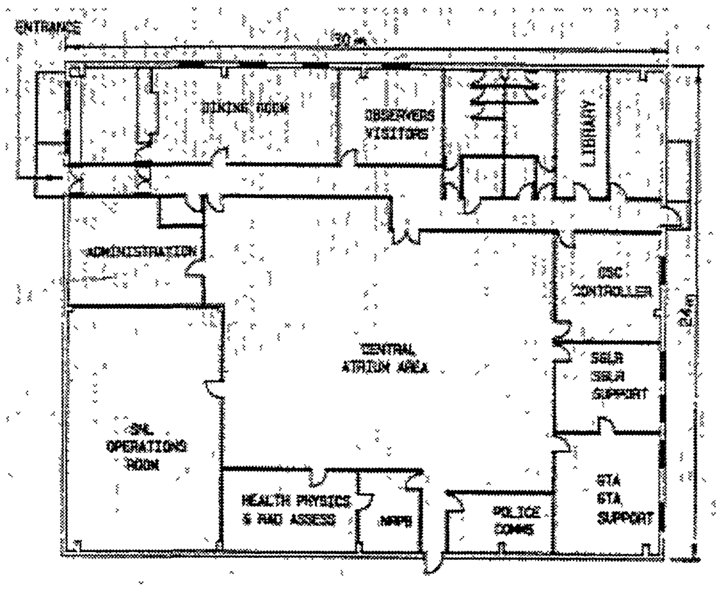


FIG. 1. Layout of Torness Off-Site Emergency Co-ordination Centre

Each OSC features accommodation for up to 150 people, diverse communications links using private and public telephone networks and radio communications. Close to each OSC a centre for briefing the media has been identified and direct communications links with the OSC installed.

The OSC internal organization structure was also changed so that the co-ordination of operations in the OSC during the early stages of an accident would be carried out by the Senior Police Officer for the Region, rather than the operator (this reflects the arrangements for other types of civil emergency) The opportunity was also taken to clearly define the areas of responsibility of the various organizations in the event of a nuclear accident (see Figure 2).

OPERATOR	EMERGENCY SERVICES	LOCAL GOVERNMENT/ AGENCIES	NATIONAL GOVERNMENT
Site Safety	Coordinating the initial response	Coordinating the recovery actions	Safety Advice (through national agencies)
Radiological Surveys (out to 15km)	Implementing measures to protect the public	Care of Casualties	Disposal of contaminated materials
Advice on early countermeasures	Control of access to the affected area	Health Monitoring	Foodstuff restrictions
		Decontamination	
		Care of evacuees	

FIG. 2. Summary of responsibilities in the event of a nuclear accident in the UK

3. DISTRIBUTION OF INFORMATION

Experience from past accidents and exercises has demonstrated the importance of supplying accurate and easily understandable information as quickly as possible to all emergency and public organizations. This is essential, not only for the implementation of any possible short term countermeasures that may be required, but to reassure those living close to the site who would quickly be made aware of any accident by the broadcast media.

To improve the distribution of information in an emergency, SNL developed a computerised Nuclear Emergency Information Management System (NEIMS) to compile and automatically distribute data to other response centres, national agencies and the media.

The NEIMS code consists of a series of databases into which information on the incident is entered. The NEIMS regularly compiles bulletins and these are distributed within the OSC and to local and national emergency centres electronically. Material for release to the media is distributed in a similar manner.

The NEIMS has been tested in a number of exercises and has proved to be very effective, with data sometimes reaching external centres before their representatives in the OSC! The specification of a phase II system utilising automatic data gathering and modern data display features is currently being developed. It is noted that other companies in the UK are now following SNLs lead in this area.

4. RADIOLOGICAL SURVEYS

In the early phase of an accident decisions on the introduction of countermeasures would be based on the advice of SNL emergency response staff who would conduct ground based radiological surveys close to the site using specialist survey vehicles. Initially the gross beta/gamma air activity together with information on the nature of the accident would be used to assess the present and future off-site hazard.

As more detailed results become available, radiological survey and meteorological data would be fed by NEIMS to an assessment computer which would provide predictions on the possible longer term effects of the accident.

Following the cessation of the release and dispersal of the plume, considerable pressure will be brought to bear on the operator to provide accurate information on deposition levels and the extent of the affected area.

To improve on the existing ground based surveying techniques SNL has been studying the practicalities of conducting post accident airborne surveys and has recently commissioned the Scottish Universities Research and Reactor Centre to conduct airborne surveys around its sites.

The surveys utilise large array Sodium Iodide detectors, radioaltimetry and Satellite Global Positioning techniques to provide quantitative information on ground deposition levels (ref 1). The survey equipment is mounted on a standard instrument rack which can quickly be loaded onto a civil or military helicopter, this has the advantages of being readily demountable in the event of contamination of the helicopter and is considerably cheaper than using a dedicated aircraft.

Preliminary survey results have revealed variations in the background radiation levels around each site of up to 50% of the mean. These variations can be related to a combination of geological features and artificial sources such as Chernobyl fallout (Figure 3). Some of the features detected during the airborne surveys had not been found in earlier ground based measurements due to localised background variations.

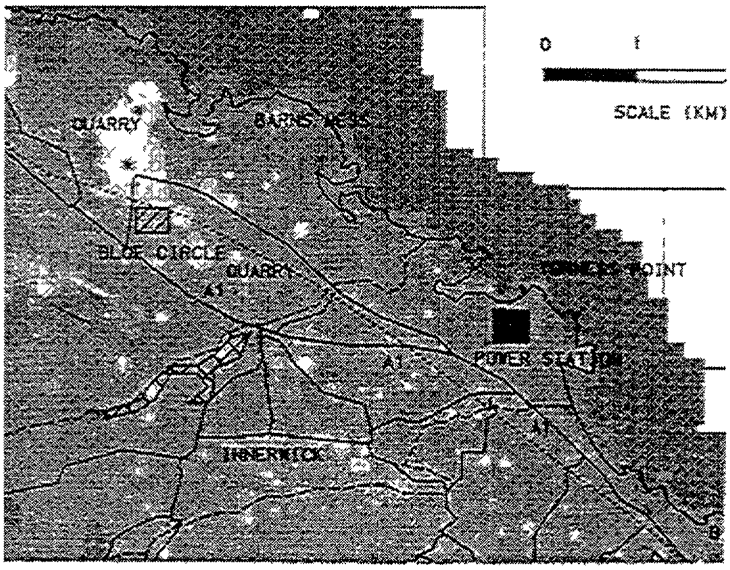


FIG. 3. Airborne background radiation survey of area Surrounding Torness Power Stn. May 1994 — Bi-214 deposition levels

Note: Enhanced levels associated with stone quarry to the West of the site.

Limits of detection for homogeneous deposition are approximately 2kBq/m^2 for Cs^{137} spatially averaged over 300m.

It is proposed that in the post release phase of an accident the survey helicopter would fly an initial, pre arranged survey pattern at 10km, 5km, and 3km from the site. On completion of this initial survey the helicopter will land close to the OSC where the data will be downloaded and analysed to determine the approximate magnitude and pattern of the deposited activity. It is anticipated that the results of the initial survey would be available within 1-2hours of the helicopter arriving at the site.

Once the general extent of the contamination has been determined a series of grid lines would be flown over the affected area. Ground based spectroscopic analysis of deposited activity would be used in conjunction with the helicopter surveys to determine the isotopic mix of the deposited activity.

It is anticipated that this data would be available within 24h of an accident.

Once the detailed survey of the affected area has been completed, rapid surveys over unaffected areas close to the site will be carried out for reassurance purposes.

It is hoped to exercise these arrangements at a forthcoming 2 day exercise at Torness.

5. CONCLUSIONS

With these initiatives Scottish Nuclear has demonstrated a commitment in both financial and resource terms that has placed the company at the forefront of emergency preparedness in the UK.

The arrangements described have been developed and implemented in close consultation with local agencies in order to ensure they satisfy local requirements. The value of consultation is recognised by all parties and Scottish Nuclear are committed to continuing this process to ensure that our emergency arrangements continue to meet national and local requirements.

REFERENCES

[1] SANDERSON, D.C.W., SCOTT, E.M., BAXTER, M.S., Use of Airborne radiometric Measurements for Monitoring Environmental Radioactive Contamination, IAEA SM-306/138, 41–421, Vienna (1990).

INTERVENTION STRATEGIES FOR THE RECOVERY OF RADIOACTIVE-CONTAMINATED ENVIRONMENTS

XA0054902

J. GUTIÉRREZ, C. VÁZQUEZ
CIEMAT,
Madrid, Spain

Abstract

INTERVENTION STRATEGIES FOR THE RECOVERY OF RADIOACTIVE-CONTAMINATED ENVIRONMENTS.

Following an accident with environmental consequences, intervention may be necessary. The type of remedial actions and the strategy required will be dependent upon, inter alia, the phase and conditions within the contaminated scenario. Leaving aside the basic countermeasures (such as confinement, evacuation), which are based on internationally agreed Generic Intervention Levels (GIL's), the paper deals with intervention strategies leading to a return of the contaminated site to as close to normality as possible with the lowest social cost. The reduction of the damage from the existing contamination must be justified and optimised; the best strategy for applying recovery actions must be selected from a set of potential alternatives. A methodology for intervention strategies analysis, developed in the framework of CEC–CHECIR ECP–4 "Decontamination Strategies", is presented together with some examples of application.

1. INTRODUCTION

This paper explains the Centro de Investigaciones Energeticas Medioambientales y Tecnologicas (CIEMAT) design for optimising decontamination strategies for the recovery of contaminated scenarios using cost benefit analysis. The work has been developed as a part of the CEC/CHECIR ECP–4.

The scope of the proposed methodology is only radiological, trying to minimise the radiological risk of the population with the lowest possible social cost, taking into account all the subsidiary factors that can be expressed in monetary terms.

The procedure starts with the characterisation of the scenario, classifying it into elemental intervention units (EIU) and with the identification of the available intervention procedures or countermeasures. Then, the criteria or factors of influence for the countermeasure's response are defined and the behaviour of each procedure over the different EIUs is quantified according with the selected criteria. A Specific Intervention Level (SIL) can be calculated for each procedure over each EIU where the countermeasure applies. This makes it possible to classify the different intervention options according to the net benefit obtained. Finally, the available budget and other social and political aspects will determine the extent of the intervention, and therefore, the intervention strategy.

This method of analysis can be implemented on a simple PC support. Default values are supplied for the different criteria considered in the analysis, but also input capability is provided for the introduction of alternative values. This software must be updated periodically as the technological capabilities in decontamination procedures are evolving and economical values changing.

It would be useful that this methodology would be available "a priori", before the occurrence of any accident for several different representative environments of the different countries.

As a part of the CEC/CHECIR ECP–4 a case-study (Kirov-Byelorussia) has been analysed by the application of the proposed methodology.

2. MATERIAL AND METHODS

2.1. Description of the methodology

The proposed framework identifies two main branches of activity on which the strategy analysis should be based. The first one is related to the scenario of intervention requiring actions aimed at its characterisation, classification and evaluation of radiological impact. The second one deals with the decontamination procedures and their relationship with the scenario including, in addition to the assessment of their applicability and effects (positives and negatives), the calculation of Specific Intervention Levels (SIL's) for each selected countermeasure. In this context intervention scenario means the spatial and temporal unit over which an intervention can be envisaged without significant interference from the outside.

The characterisation will consist of identifying, collecting and structuring information leading to a complete description (physical, radiological, socio-economic...) of the contaminated scenario. This must allow the differentiation of the scenario in intervention units (IU's) defined as class elements of any scenario where similar activity concentrations lead to similar radiological risks and have similar response to the same countermeasure.

TABLE IA. SOFTWARE DESIGN

IU's MODULE		
OPTION	TO CREATE TO MODIFY	
	INPUT	Identification Code
		Pathways (Secondary IU's), Radionuclides, Models, Parameters
	OUTPUT	New element in IU's file
	Options	Return
		Go to Countermeasure Submodule (Option To Create)
OPTION	TO SELECT	
	INPUT	Calculation criteria Integration period, Discount factor, value
		IU's to be selected (code)
	OUTPUT	Dosimetric and economic impact (unitary)
	Options	Return
		Go to Countermeasure Submodule
		Go to Scenario Submodule
COUNTERMEASURE SUBMODULE		
OPTION	TO CREATE OR TO MODIFY	
	INPUT	Identification Code
		Parameters for the assessment of the performance (radiological and economic)
	OUTPUT	New element in Countermeasure file
	Return	
OPTION	TO SELECT	
	INPUT	Countermeasures on each IU to be analysed
		Restrictions
	OUTPUT	SIL's
	Return	
SCENARIO SUBMODULE		
	INPUT	Ranges of activity for primary IU's
		Number of IU's into each range
		Restrictions on IU's
	OUTPUT	Radiological Impact from IU's in each range
		Countermeasures justified from IU's in each range
		Net Benefit, Residual Dosimetric Impact
		Residual Specific Activity and Dose Rates
	Options	Return
		Go to Strategy Submodule
STRATEGY SUBMODULE		
	INPUT	Values for restrictions on Countermeasures and IU's
		Available Budget
	OUTPUT	Selected strategy for the available budget
		Note 1 Restrictions, where they exist, must be always observed
		Note 2 The relative net benefit is the unit used in comparing countermeasures

TABLE 1. EXAMPLE OF APPLICATION

IU MODULE

INPUT	IU	PATHWAYS	PARAMETERS	CRITERIA
	Hay-land		In-Ocupancy factor 0.4	Integration period: infinite
	Milk	Ingestion	Out-Ocupancy factor 0.2	Discount factor 0.04
	Cheese	Ingestion	House occupants 4	α value($ / man-Sv) : 8000
	Rooves	Ext. irradiation		Radionuclides: Cs 137, Sr 90
	Walls	Ext. irradiation		Dry deposition
	Yard	Ext. irradiation		

OUTPUT (Impact per Bq/m^2)	Activity		Dosimetric Impact (Man-Sv/ha)		Economic Impact ($/ha)	
	Cs	Sr	Cs	Sr	Cs	Sr
Hayland (Bq/ha)	10000	10000				
Milk (Bq/l)	1.5E-3	3.7E-4	3.0E-6	2.0E-6	0.024	0.016
Cheese (Bq/Kg)	2.2E-5	2.1E-4	4.5E-8	1.1E-6	3.6E-4	8.9E-3
	Ind. Dose rate		(Man-Sv/house)		($/house)	
	In	Out	Cs	Sr	Cs	Sr
Rooves (μSv/d)	4.0E-3	8.8E-5	4.9E-5		0.393	
Walls (μSv/d)	2.9E-4	1.6E-3	2.3E-5		0.0108	
Yard (μSv/d)	8.0E-3	8.7E-2	1.1E-3		9.15	

COUNTERMEASURES SUBMODULE

INPUT	Countermeasure	Decont. Factor		Cost	OUTPUT	SIL's (KBq/m^2)
		Cs	Sr			
	Turf harvester (Hayland)	20	3	2025 ($/ha)		186
	Deep ploughing (Hayland)	20	3	825 ($/ha)		76
	Cheese (option 1)(Milk)	0.75	3.72	2.5E-4 ($/l)		2.5 (Bq/l)
	H.P. water (Rooves)	1.7		1 ($/m^2)		3500
	H.P. water (Walls)	1.8		0.2 ($/m^2)		3200
	Digging (Yard)	3.8		1 ($/m^2)		2050

TABLA 1. EXAMPLE OF APPLICATION (CONT.)

SCENARIO SUBMODULE

INPUT			OUTPUT (Hayland)				
Range of deposition (central value) (Bq/m2)		Hayland (ha) / Houses (number)	Economic value of the dosimetric impact ($)		Justified countermeasures (net benefit $)		
Cs	Sr		By milk	By cheese	Turf (milk)	Plough (milk)	Cheese
7.5E3	7.5E2	10 / 3	1942	95			16
3.0E4	3.0E3	20 / 4	15534	762			274
7.5E4	7.5E3	20 / 6	38834.	1905		19698	761
3.0E5	3.0E4	12 / 3	93202.	4571	62838	76976	1917
7.5E5	7.5E4	8 / 2	155337	7618	129029	138193	3224
3.0E6	3.0E5	4 / 1	262162	14512	236127	240200	6725
7.5E6	7.5E5	2 / 1	388342	19045	359023	360331	8106

INPUT		OUTPUT (Houses)					
Range of deposition (central value Bq/m2)		Economic value of the dosimetric impact ($)			Justified countermeasures (net benefit $)		
Cs	Sr	Walls	Rooves	Yard	H.P. water (walls)	H.P. water (Rooves)	Digging (Yard)
7.5E3	7.5E2	0.2	0.9	11.2			
3.0E4	3.0E3	1.0	4.7	59.5			
7.5E4	7.5E3	3.9	17.5	223.1			
3.0E5	3.0E4	7.8	34.9	446.2			
7.5E5	7.5E4	12.9	58.3	743.7			
3.0E6	3.0E5	25.9	116.5	11487.5			347.7
7.5E6	7.5E5	64.8	291.3	33718.7	13.5	65.4	1994.2

STRATEGY SUBMODULE

INPUT Maximum milk production to make cheese: 80000 l/y
GIL for permanent resettlement : 1 Sv/lifetime
DIL for Sr-90 in milk : 0.1kBq/l
GIL for relocation : 30 mSv/month
DIL for Cs-137 in milk : 1 kBq/l
Budget available : 25000 $

OUTPUT : Classification of compatible cost effective countermeasures taking into account input restrictions

Range (Bq/m^2)	Rel. ben.	IU / count.	Inver-sion ($)	Accum. ($)	Range (Bq/m^2)	Rel. ben.	IU / count.	Inver-sion ($)	Accum ($)
7.5E6	**218**	**plough+ cheese**	**1655**	**1655**	**7.5E6**	**2.7**	**digging**	**750**	**22215**
3.0E6	**73**	**plough+ cheese**	**3310**	**4965**	7.5E4	1.2	plough	16500	38715
7.5E5	**21**	**plough**	**6600**	**11565**	7.5E6	1.1	HPwat. R	58	38773
3.0E5	**8**	**plough**	**9900**	**21465**	7.5E6	1.0	HPwat.	13	38786

Typical IU's for urban environments are paved streets, public gardens, walls, roofs and gardens of buildings, etc.; the different building materials and type of buildings (multi-storied/single, public/private) can result in different IU's. Concerning agricultural environments the aspects which influence the radiological impact such as soil texture, pH, organic matter, irrigated or dry farming, destination of production, etc. must be taken into account in obtaining IU's. Lands where rotation of crops is a common practice, haylands and fruit orchards are typical examples. In natural or seminatural environments, forest, scrubs and pasture lands will be IU's in most cases.

The above examples of IU's can be considered as primary IU's because they are elements where the contamination is directly deposited. Other secondary IU's where the contamination is the result of activity transfers through different pathways (foods, wood, underground water, etc.) could also be identified. Almost all of the attributes characterising IU's would be suitable to be known before an accident occurs.

One of these attributes is the set of parameters influencing the future behaviour of the deposited activity on the IU. For example if the IU is the ceramic file roof in single family homes, the models for geometry, building material and occupancy factor need to be previously defined. In the case of haylands the soil factors (texture, pH, CEC) and information on practices and production rates will be the typical parameters.

Another IU attribute is the radiological impact that it will produce. It is possible to calculate a normalised (per unit of deposited activity) impact in terms of dose rates and integrated doses (infinite) for each IU identified. Relevant tasks to achieve this will be the identification of exposure pathways from each primary IU and the assessment of radioactivity transfer along the components (secondary IU's potentially to be cleaned-up as an alternative to the clean-up of the primary ones) of the pathway.

The geographical distribution of potential IU's in the scenario is also an attribute suitable for prior evaluation. Since the preparedness for emergency will use GIS representing the measured or estimated activity distribution on the contaminated scenario, the range of contamination over each IU, after the accident occurs, can be obtained by overlapping both maps. A few ranges of activities must be set up for each IU and radionuclide. Then the amount of IU components belonging to each range will be evaluated in order to obtain criteria in deciding the application of countermeasures.

Analysing decontamination procedures will consist of an assessment of their performance, applicability and adaptability when applied to IU's. The performance criteria characterising the radiological and economic behaviour of each technique on each IU (and for one specific radionuclide) must therefore be identified.

The radiological efficiency of a decontamination procedure will be evaluated in terms of a decontamination factor, averted dose and added risk to the workers. Factors influencing the efficiency must be taken into account.

The economic impact will include the operation costs and the costs concerning waste management and disposal as a consequence of the intervention. The assessment of indirect consequences (negative and positive) produced by the clean-up technique, such as secondary contamination, ecological damage, changes in productivity and/or quality of foods, indirect health effects, etc., will also be made in monetary terms.

The above parameters will make it possible to calculate the SIL of the countermeasure. In this context SIL means the minimum value of the activity concentration on the IU that would justify the application of the countermeasure.

2.2. Software Design

Given the need to have available a tool for rapid analysis, the above methodology is being implemented as a PC software the structure of which is shown in the Table IA.

3. RESULTS

Applying the proposed framework, Table I shows the results obtained in the analysis of a hypothetical case study. The example consist of a dry deposition of Cs and Sr over a rural settlement with single family brick houses of 50 m^2 and having a surrounding yard of 800 m^2 each. The settlement has 76 ha of haylands for milk (10000 l/ha) and Brynza cheese (from the 10% of produced milk) production. Data on contamination, IU's, pathways, countermeasures, parameters and criteria considered for calculation are also shown in Table I. Although the values used are as real as possible the results must only be interpreted as a positive test for the proposed methodology and not as a judgement of the involved countermeasures.

XA0054903

ARGOS–NT: A COMPUTER BASED EMERGENCY MANAGEMENT SYSTEM

ST. HOE
Emergency Management Agency

S. THYKIER-NIELSEN
Risø National Laboratory

L.B. STEFFENSEN
Prolog Development Center

Denmark

Abstract

ARGOS–NT: A COMPUTER BASED EMERGENCY MANAGEMENT SYSTEM.

In case of a nuclear accident or a threat of a release the Danish Emergency Management Agency is responsible for actions to minimize the consequences in Danish territory. To provide an overview of the situation, a computer based system called ARGOS–NT has been developed in 1993/94. This paper gives an overview of the system with emphasis on the prognostic part of the system. An example calculation shows the importance of correct landscape modeling.

1. INTRODUCTION

Denmark has no nuclear power plants of its own, but is surrounded by 11 reactors operating within a distance of 200 km from its borders. Of these 11 reactors, 2 are placed only 20 km from the center of Copenhagen which has 1 million inhabitants. All the surrounding reactors are of western design with filtered containments, but in emergency planning, one must never disregard the rest risk from such installations.

In the early eighties the Risø National Laboratory developed the first UNIX based ARGOS system (Accident Reporting and Guiding Operational System) to manage measurement in the case of a nuclear emergency. In 1993/94 the system has been totally redesigned, and today the system is implemented as a graphical Microsoft Windows NT application. ARGOS–NT has today become a central part of the Danish nuclear emergency system.

The system can collect and present measurement data from mobile units, on-line measuring stations and helicopters, and includes the atmospheric dispersion model RIMPUFF, which can calculate a prognosis in less than 15 minutes.

2. SYSTEM OVERVIEW

ARGOS–NT relies heavily on a graphical presentation of measurement data and the calculations performed on these. The core of the system is a client/server database that stores measurement data collected from all parts of Denmark. The data are entered on-line and can be accessed and approved by centrally placed experts. The measurement data comes from a variety of sources. These include:

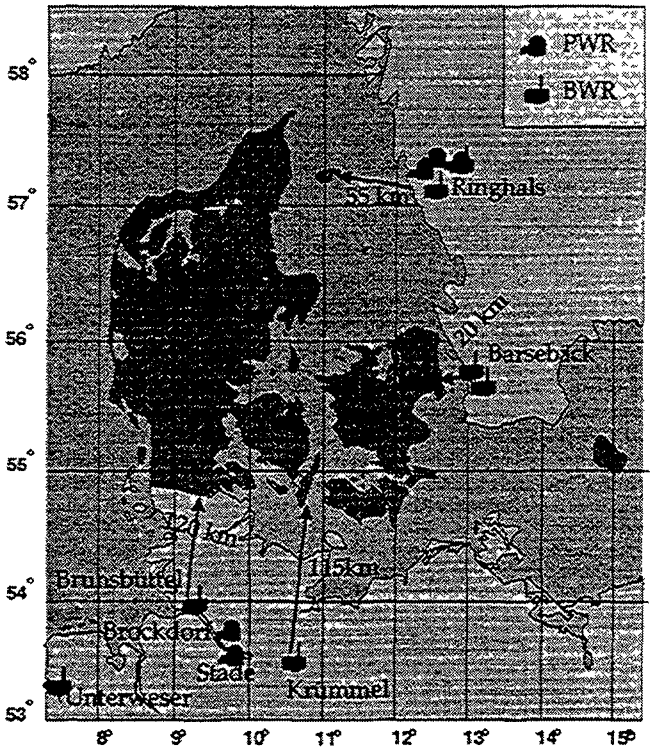


Figure 1: Nuclear Plants Around Denmark

- Mobile units that measure dose rates at points along pre-defined routes.
- Mobile units that measure air-concentration in specific areas.
- Mobile units that collect environmental samples.
- Permanent on-line measuring stations that are equipped with ion chambers, scintillation detectors and precipitation detectors.
- Pre-processed data from airborne systems.

The presentation of the measurement data is centered around geographical maps on which data and calculations can be overlaid:

- Actual measurements presented as colored points.
- Isodose and deposition calculations presented as curves and/or colored areas.
- Prognosis for deposition, air concentration and gamma doses from released radioactivity, presented as puffs and/or colored areas.

3. THE ATMOSPHERIC DISPERSION MODEL — RIMPUFF

The Risø Mesoscale PUFF model (RIMPUFF) (Thykier-Nielsen and Mikkelsen, (1993)) can calculate prognosis for multiple isotopes simultaneously, and uses wind and rain data from the Danish Meteorological Institutes numerical weather model (Machenhauer et al. (1991). The wind data are updated twice a day and include a 36 hour forecast.

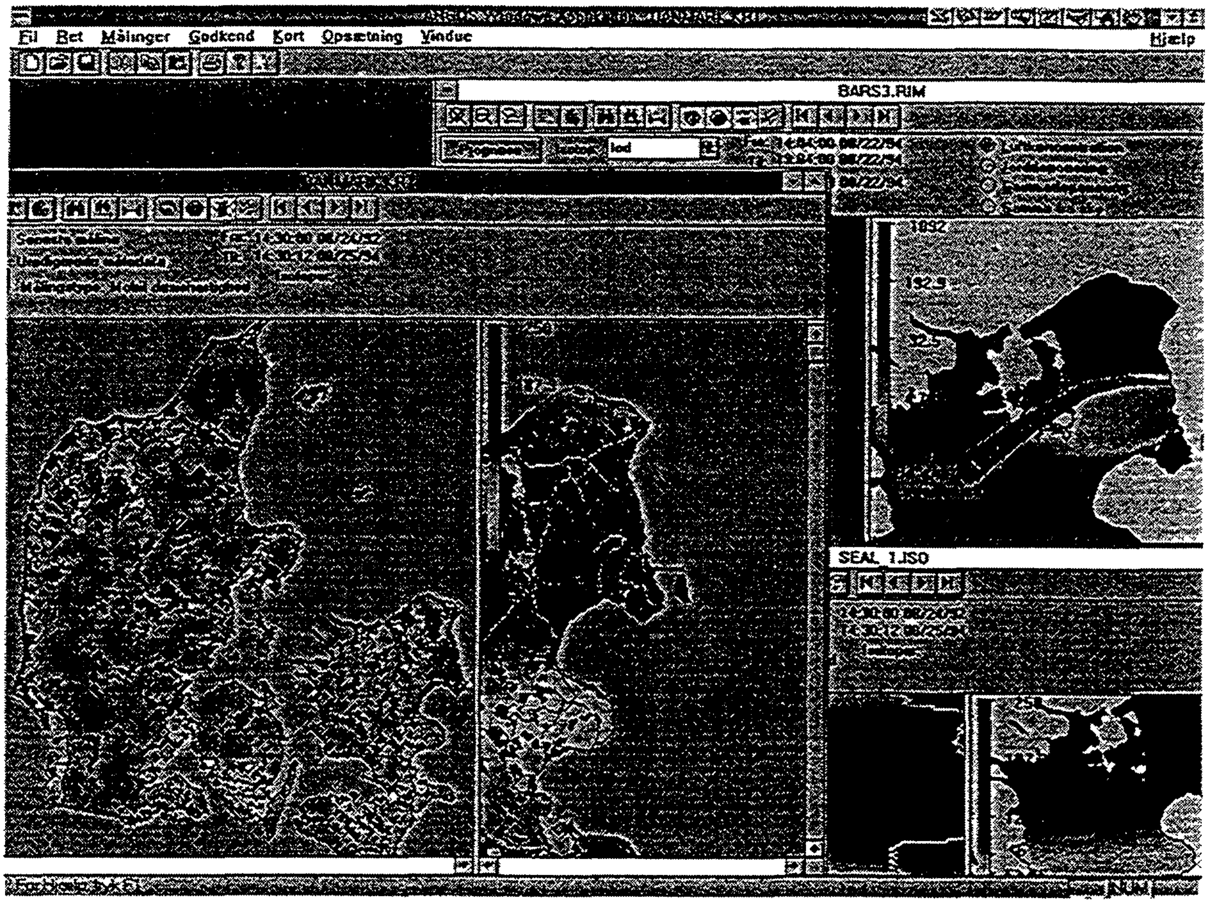


Figure 2: ARGOS_NT Map, Prognosis and Isodose documents

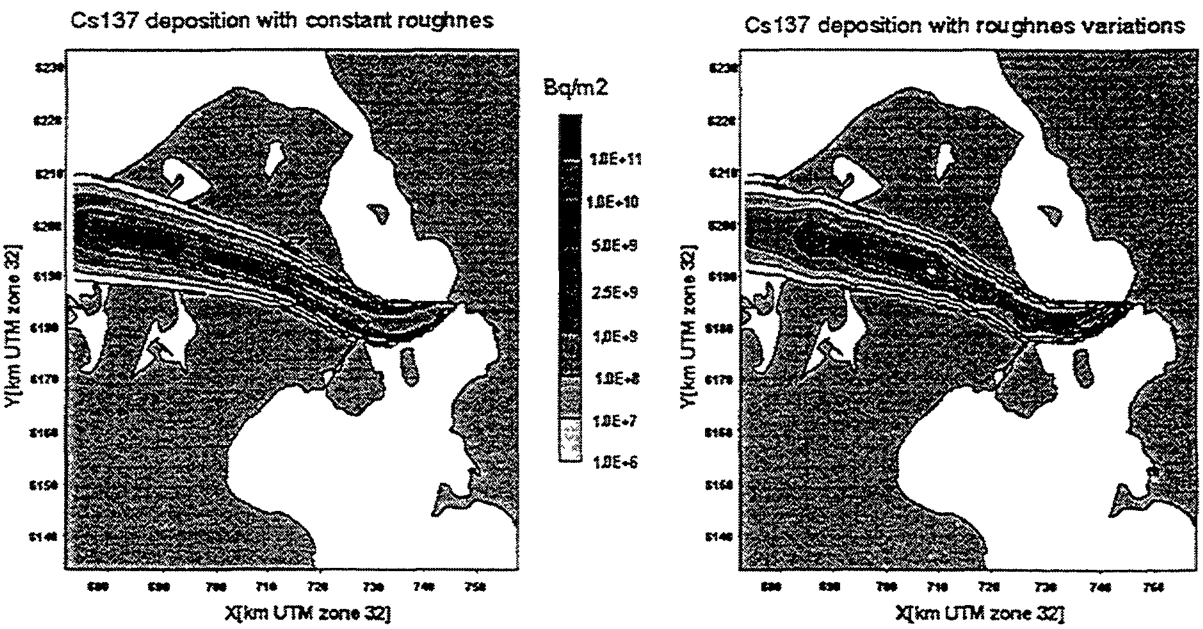


Figure 3: Cs -137 deposition a) with constant roughness
b) with roughness variations

exception is for noble gases, though. Groundshine can be an important contributor for both short and long term dose rates. Furthermore the deposition on rural surfaces is important notonly from the viewpoint of doses to the rural population but also due to its impact on food contamination (via crops and livestock).

Deposition can be separated into dry and wet deposition, of which only the former is dealt with here. Dry deposition rates are different for gases and particles, and both are highly controlled by the surface, so different materials have different deposition to different surfaces. The factors influencing dry position can be divided in three groups (Hummelshøj, (1994)):

Micrometeorology:	Atmospheric stability, wind speed, inversion layer
Material:	Particle size, solubility, hygroscopicity, reactivity
Surface:	Surface type, roughness, canopy structure, wetness

As many of these factors are difficult to measure and parameterise, only a few are used in practical atmospheric dispersion models. In RIMPUFF dry deposition is modeled using the so-called source depletion model, where dry deposition for a given material is characterized by a deposition velocity, which is specified as a function of atmospheric stability and wind speed (Thykier–Nielsen, and Larsen, (1982)). In the new version of the model the surface type is also taken into account. This is done in characterizing each type of surface (urban, rural, forest and water) by its surface resistance, which primarily is a function of surface roughness and friction velocity (for a given material) (Hummelshøj (1994), Jensen (1981), Roed (1990), Asman et. al. (1994)). For 1μ Cs137 particles the resulting dry deposition velocities are assumed to be (Panitz et. al. (1989)): rural areas (grass) = 0.001 m/s, forest = 0.002 m/s, urban = 0.0001 m/s and water = 0.0001 m/s (dependent on wind speed). The difference between urban and forest is due to differences in surface area.

It should be borne in mind that this is a simplified picture, but, for most accident scenarios this is a reasonable solution.

5. SAMPLE CALCULATION

To illustrate the significance of taking into account the surface type in the assessment of consequences of radioactivity releases, the following scenario has been considered: A 1 hour release from the Swedish Barsebäck reactor located about 20 km from Copenhagen. It is a summer situation with moderate easterly to south-easterly winds and neutral stability. Wind and stability data are based on the Øresund experiment. The meteorological data are updated every 10 minutes. The area considered for the calculations is 85 by 98 km. The material passes over water for about 20 km before it reaches the coast of Sjælland.

The resolution of the grid used for the calculations is 500 m X 500 m. Each grid square is assigned a roughness class: urban, rural, forest or water. Calculations of integrated ground concentrations have been made with 2 types of dry deposition models:

a) No dependence on deposition from surface roughness, i.e. the roughness in the entire area is the same = rural areas.
b) The area is classified in roughness classes as described earlier.

Further 3 release heights are considered: 50 m, 95 m and 500 m, and 3 isotopes: J^{131}, J^{131} organic and Cs^{137}.

The results for Cs^{137} released at the height 95 m are shown in Fig.3.

Fíg.3a shows the first type of deposition modeling (no roughness classification) and Fig. 3b the same situation taking into account the roughness classification. There is a significant change of the deposition pattern, when the roughness variation is allowed for. Deposition and thus gamma doses in the urban area close to the coast are reduced by a factor of 2–3. Deposition over the rural area close to the city is increased about 20–50% while there are only small changes in the amount deposited at longer distances.

For higher release heights and/or isotopes with lower deposition rate the influence is less significant and vice versa.

It is difficult to make a general conclusion from the calculations described here, as the surface types in the environment of different nuclear power plant are not the same. However, it seems that surface type and thus surface roughness, are important factors, which could have a significant influence on the consequences of accidental releases from nuclear power plants.

REFERENCES

[1] ASMAN, W.A.H., SØRENSEN, L., BERKOWICZ, R., GRANBY, K., NIELSEN, H., JENSEN, B., RUNGE, E.H., LYKKELUND, C., GRINNING, S.-E., SEMPREVIVA, A.M., Processor for tørdeposition, Havforskning fra Miljøstyrelsen Nr. 35, Denmark Miljøundersøgelser, Forskningscenter Risø, (in Danish) (1994).

[2] HUMMELSHØJ, P., Dry Deposition of Particles and Gases, Risø National Laboratory, Risø–R–658(EN) (1994).

[3] JENSEN, N.O., A Micrometeorological Perspective on Deposition, Health Physics, Vol. 40 (1981) 887–891.

[4] MACHENHAUER, B., NIELSEN, U.B., RASMUSSEN, A., Evaluation of the Quality Especially of Wind-forecasts by the Operational Meteorological HIRLAM-system, Proceedings of the OECD/NEA Specialists' meeting on Advanced Modeling and Computer Codes for Local Scales and Meso-scales Atmospheric Dispersion of Radionuclides and their Applications (AD–LMS'91), Sarclay, France, OECD Publication No. 75907 (1991) 152–163.

[5] PANITZ, H.-J., MATZERATH, C., PÄSLER-SAUER, J., UFOMOD Atmospheric Dispersion and Deposition, KfK 4332, Kernforschungszentrum Karlsruhe (1989).

[6] ROED, J., Final Report of the NKA Project AKTU–245: Deposition and Removal of Radioactive Substances in an Urban Area, Nordic Liaison Committee for Atomic Energy (1990).

[7] THYKIER-NIELSEN, S., LARSEN, S.E., The Importance of Deposition for Individual and Collective Doses in Connection with Routine Releases from Nuclear Power Plants, RISØ National Laboratory, Risø–M–2205 (1982) 56 pp.

[8] THYKIER-NIELSEN, S., MIKKELSEN, T., Modeling of Flow and Dispersion in a Coastal Area, Proceedings from a EURASAP Conference, Workshop III on the Øresund Experiment, Risø National Laboratory, Denmark, 25–27 October 1988.

[9] THYKIER-NIELSEN, S., MIKKELSEN, T., RIMPUFF USER'S GUIDE (Version 33 PC version), Available on request from: Department of Meteorology and Wind Energy, Risø National Laboratory, P.O. BOX 49, DK 4000 Roskilde (1993).

PARATI — A PROGRAM FOR RADIOLOGICAL ASSESSMENT AFTER RADIOACTIVE CONTAMINATION OF URBAN AREAS

E. ROCHEDO, L.F. CONTI
Instituto de Radioproteção e Dosimetria/CNEN,
Rio de Janeiro, Brazil

H.G. PARETZKE
GSF–Institut für Strahlenschutz,
Oberschleißheim, Germany

Abstract

PARATI — A PROGRAM FOR RADIOLOGICAL ASSESSMENT AFTER RADIOACTIVE CONTAMINATION OF URBAN AREAS.

A dynamic model aimed on the assessment of the long-term consequences of an accidental contamination of urban environments has been developed. The model was designed to assess the radiation exposure, as a function of time, of the different kinds of people that uses the contaminated environment, the relative contribution of each exposure pathway to simulate the application of countermeasures and its effects on the reduction of surfaces contamination and on the exposure of the individuals and of the population. The model is an empirical one, mainly based on environmental data gathered after the Chernobyl and Goiânia accidents, and takes into account climatic and population habits characteristics of tropical areas. The model was applied here to a contamination with the radionuclide ^{137}Cs but can be easily adapted to other nuclides by changes on parameter values. An analysis of the variabilities associated to the model outputs regarding population habits, different kinds of urban environment and parameters uncertainty has shown that the main source of uncertainty on model predictions is associated to a correct knowledge of population characteristics, its habits and uses of the contaminated environment.

1. INTRODUCTION

The PARATI model was developed to assess the dose for individuals of the public, resulting from the radioactive contamination of urban and semi-urban environments, in order to evaluate the radiological consequences of the accident and to suggest the adequate countermeasures. PARATI was then designed to assess the resulting cumulative radiation doses, as a function of time, for different kinds of people, to indicate the fractional contribution to these doses from each pathway, and to point out the relative effectiveness of protective actions regarding dose reductions.

The design of the PARATI model is focused on the assessment of the medium and long term consequences of an accidental liberation. It has its starting point when the material is already deposited on the environment, after the passage of the radioactive cloud. The model presented in this paper is applied to the assessment of consequences of a contamination of an urban environment for the radionuclide ^{137}Cs. However, it will be extended in the future also to several other nuclides through the application to specific parameter values.

2. MODEL STRUCTURE

2.1. Exposure Pathways

The exposure pathways considered in PARATI include:

- external beta and gamma irradiation due to the deposited material
- external beta and gamma irradiation due to resuspended activity

- internal irradiation through inhalation of resuspended activity
- internal irradiation due to ingestion of contaminated foodstuff.

Several studies, field data and transfer or exposure models were used to compose the PARATI model. Whenever possible, it was preferred to use post-Chernobyl data, together with results from the Goiânia project (Amaral et al. 1992, Pires do Rio 1993). The time behaviour of the activity on surfaces and the contribution of each surface to the exposure fields are estimated for each location of the urban environments following the model developed by Jacob and Meckbach (Jacob et al. 1987, Meckbach et al. 1988A, Meckbach et al. 1988B). Some parameter values were adapted from this original data set to fit tropical environments. Internal doses due to inhalation of resuspended activities are also estimted. For the external locations, the skin beta dose is also calculated. Internal doses due to the ingestion of foods produced in vegetable gardens or fruits, and products from small domestic animals such as hen meat and eggs, are also simulated by the model, as a function of the region of origin of these food products, taking into account the productivity of home vegetable gardens in urban and sub-urban areas.

2.2. Simulated Processes

Deposition in urban surfaces are estimated according to the initial deposition in a uniform horizontal lawn, the kind of deposition process (dry wet or storm deposition), and retention characteristics of each surface.

The main natural process of removal of activity from surfaces is weathering. Each surface has its own behaviour related to the loss of the initially deposited material, according to its characteristics of retention and fixation of the deposited material. The material lost by weathering is considered in the model but its transfer to any other compartment is not computed, since weathering is usually a very slow process for most common urban construction materials. Other important natural processes that modify the surfaces' activity are the radioactive decay, the recontamination of internal surfaces of houses and buildings due to deposition from airborne material and due to dust carried indoors by shoes, the resuspension of materials initially deposited on soils and lawns to the air. Migration in non-paved surfaces leads to a depletion of the surface activity and to the contamination of the deeper layers.

Up to 20 artificial processes for the removal of material deposited on surfaces can be simulated in the model. Protective measures may be applied to the same or to different surfaces anytime during the assessment period. Examples of possible measures to be simulated are the cutting of lawn, the removal of layers of soil or sand, the prune of trees, the water or chemical washing of paved surfaces, the scrapping of pavement layers and the removal of tiles or pavement layers.

2.3. Scenarios

Scenarios are considered to be a detailed description of the urban area and the correspondent description of the uses of these locations by a specific population.

2.3.1. Urban Areas

The urban area to be assessed by the model may be divided into up to 5 regions, according to the deposition pattern. Each region is then characterized by a homogeneous deposition under a specific weather condition, described by two quantities: a qualitative parameter, that refers to the kind of deposition at the region (dry, wet or storm deposition) and a quantitative parameter, that refers to the amount of radionuclide deposited in a unit area of lawn.

Each urban region contains up to 20 different urban environments. The selection of environments to be modelled must consider the four main human activities related to external exposure simulated by the model, that are residence, work or study, leisure and transit. According to this criteria, the choice of urban environments to simulate may include residential constructions, such as houses built with high or low shielding materials, buildings in row or with external gardened areas, commercial houses, office buildings, schools, indoor and outdoor leisure envirnments such as parks, beaches or playgrounds and different kinds of streets such as those with good pavement and those with cracked or even no pavements.

The urban environments are sub-divided into locations. Exposure fields are assessed, as a function of time, for all urban locations. Exposure of individuals, except the ingestion pathway, is related to the occupancy rates of the urban locations.

Different kinds of urban surfces are simulated to compose the locations, including paved surfaces such as asphalt or concrete streets, cobblestone areas, paved areas on the outside compartment of houses or building playgrounds, walls, roofs, windows, neighbouring constructions, non-paved areas such as lawns, soil or sand and other surfaces that may contribute to the external dose such as trees and internal surfaces of houses and buildings.

Other environmental compartments such as air, foodstuff and soil layers are also considered in the model.

2.3.2. Urban Population

The selection of human groups must consider the differences in activities patterns, occupation patterns and dose or risk factors. As so, individuals are characterized by age, behaviour groups and occupation pattern in the different urban environments. The model follows the individuals through time considering grow up processes.

Each individual must be described in terms of age group, behaviour group and occupation pattern, specifying the time daily spent in each location of the urban environments, relevant to the calculation, with the possibility of each individual occupying several compartments, of several environments of one or more region, according to the main human activities simulated in the model (residence, work or studying, transit and leisure activities).

2.3.3. Simulated Scenario

The results presented in this work refer to an urban area composed of residential houses built in high and medium shielding material, office building in a row and park areas. Three population groups considered are:

- residents that live in high shielding houses
- resident that live in low shielding houses
- weekend visitors, staying in high shielding houses and using park areas for leisure activities.

Each of these groups is sub-divided into seven age groups. The basic scenario is related to a dry deposition of 1 $kBq.m^{-2}$ in a smooth and uniform lawn surface.

3. MODEL RESULTS

Outputs of the model include the time dependent activity concentration on surfaces and air, kerma rates for all urban locations, dose rates, integrated doses and lifetime risk for individuals, groups of individuals and for the population as a whole, and the effect of protective measures in reducing these doses. The doses calculated in the model are the

Effective Equivalent Dose for the external exposures and the Committed Effective Equivalent Dose for the internal exposures. For the characterization of groups or population, it is used the average individual dose instead of the collective dose because the first one is independent of the number of persons composing the groups or the population.

The model also computes the input of contaminated materials to a sink region, by making the estimate of the amount of contaminated material that is removed by decontamination procedures, per unit area of the surface to which it was applied. This data can be used as input for the assessment of material that will be brought to waste repositories or to other outside areas such as garbage systems or rain water drains. Some examples of model results are given below:

3.1. Surfaces

The model estimates the time behaviour of the activity deposited on surfaces after the initial deposition event (Fig.1). It can be seen that each surface has a characteristic behaviour, according to its retention and weathering properties. This kind of deposition affects the initial retention by surfaces but not the subsequent weathering characteristics (Fig.2).

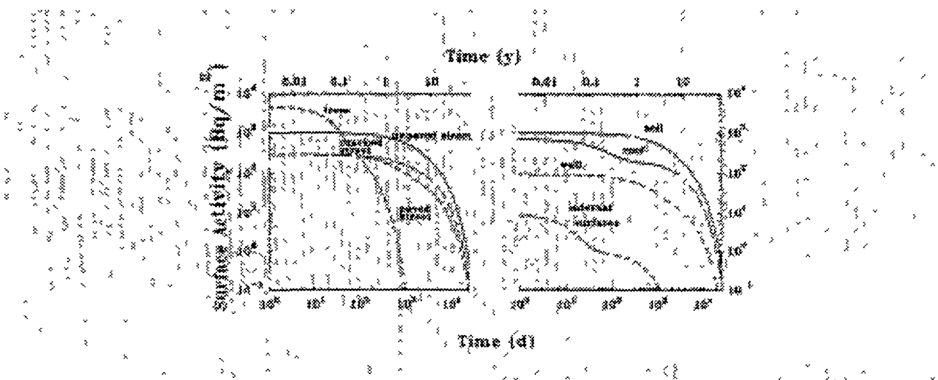


Figure 1 - Time behaviour of deposited activity in urban surfaces for a dry deposition of 1 kBq.m^{-2} in a smooth and uniform lawn surface

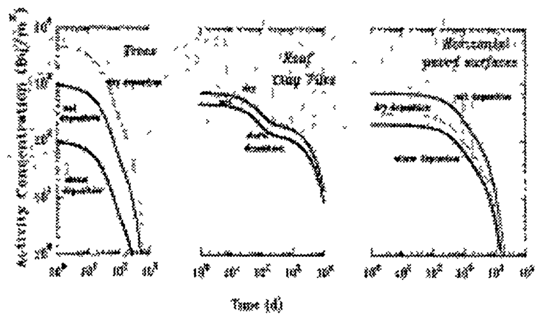


Figure 2: Activity per unit area of three different surfaces for different kinds of depositions.

3.2. Exposure fields

The exposure fields are assessed for all urban locations according to the contribution of all surfaces to this exposure (Fig.3, where main surfaces contributing to the exposure fields are shown, for two locations of an urban environment).

Figure 3 - Main surfaces contributing to exposure fields of different urban locations of a low shielding house (also included the effect of radioactive decay alone on outdoor soil surface)

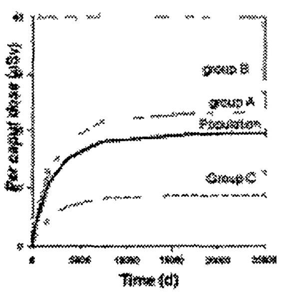


Figure 4. Population and groups integrated doses

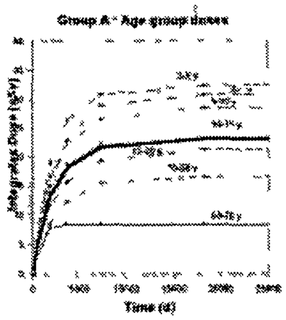


Figure 5 Age groups doses for habit group A

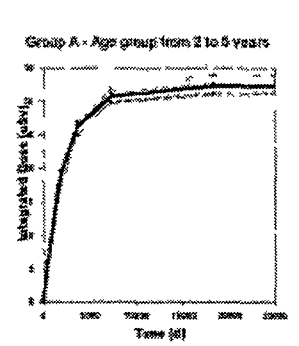


Figure 6 Individuals doses for age group from 2 to 5 years at the time of the accident

3.3. Dose Results

The doses are presented, as a function of time, for the population (per caput dose), average for habits groups (Fig.4), average for age groups (Fig.5), or individually (Fig.6).

The contribution of surfaces to the individual doses can also be assessed, as exemplified in Table I.

Surfaces Contribution to Group Doses (%)

Population Group A

Time	roof	wall	lawn	trees
first day	16	1	38	41
first year	14	2	74	8

Table 1. Percent contribution of surfaces to population exposure

3.4. Countermeasures

The effect of the application of protective measures is assessed by the model through the estimate of dose reduction. As an example, Table II shows the results obtained for the application of a countermeasure of removing a small layer (1 cm) of top soil. It can be seen the effect of the protective measure for different kinds of deposition, and, for a dry deposition the effect of the time of implementation of the measure on the reduction of the population dose:

Removal of 1 cm Soil Layer from Residences

(% dose reduction)

Kind of Deposition	Removal time	first year	lifetime
dry	120	33	53
wet/low	120	34	52
wet/high	120	37	56
dry	60	45	58
dry	120	33	53
dry	180	22	48
dry	365	0	35

Table 2· Percent dose reduction due to countermeasures 1 cm top soil removal

4. VARIABILITIES AND UNCERTAINTY ANALYSIS

An extensive analysis of variabilities due to differences in urban environments, between individuals and its uses of the urban area, and a parameter uncertainty analysis were carried out (Rochedo 1994) and compared with respect to the variability on the population dose. Differences between individuals can be responsible for about one order of magnitude variability on model results (Fig.7), with coefficients of variation (CV) about 0.45 for the simulated scenario, for integrated average population lifetime dose and a CV about 0.11 for individuals in the same age group. The characterization or urban locations can lead to a CV in the range of 0.15 to 0.30. Different uses of a same urban area can lead to a variability on the dose results of 0.5 to 0.6. Parameters uncertainty analysis was performed using the program PRISM (Gardner 1990) and can lead to CV from 0.15 to 0.30, with a complex variation feature along the assessment period, as can be seen in Table III, which shows the main processes and main surfaces contribution to the uncertainty of model results for different times of the assessment period. The comparison of effects on dose results are summarized in Figure 8, for the lifetime average population integrated dose.

5. CONCLUSIONS

The assessment of future trends of population exposure is a necessary tool for the decision process after an accidental contamination. Several aspects related to long term behaviour cannot be precisely foreseen and the follow up of accident consequences is important for the future validation of the model results. For the simulated scenario and for the radionuclide ^{137}Cs, the main pathway is the external exposure to the deposited activity, with the main contribution due to the non-paved surfaces. Trees show a relevant contribution, mainly for the short term, and roofs have also significant contribution to population exposure. The main source of uncertainty is related to an adequate knowledge of the population and the correct characterization of its habits and uses of the environment.

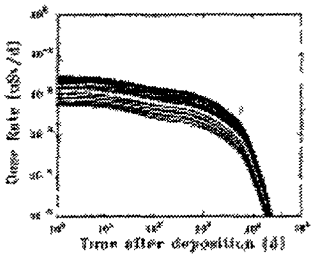


Figure 7. dose rates for 105 individual of the simulated scenario

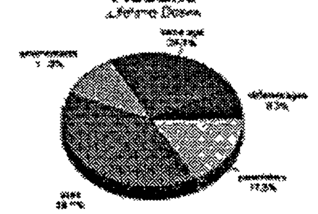


Figure 8 Comparison of different sources of variability of model results

Parameter Uncertainties

(% contribution to total uncertainty)

Process	Surface	first day	lifetime
Deposition	soil	23	11
	trees	58	<1
	roof	1	11
Weathering	soil	1	40
External gamma	soil	3	21
	trees	9	<1
	roof	<1	6

Table 3· Coefficient of variation due to uncertainty of parameters

REFERENCES

[1] AMARAL, E.C.S., PARETZKE, H.G., PIRES DO RIO, M.A., CAMPOS, M.J., Radioecological Measurements after the Goiânia Accident — in Radiation Research: A Twentieth Century Perspective, Volume II: Congress Proceedings, (DEWEY, W.C., EDINGTON, M., FRY, R.J.M., HALL, E.J., WHITMORE, G.F., Eds.), Academic Press, Inc., USA (1992).

[2] JACOB, P., MECKBACH, R., Shielding Factors and External Dose Evaluation, Radiation Protection Dosimetry V.21 No.1/3 (1987) 79–86.

[3] MECKBACH, R., JACOB, P., PARETZKE, H.G., Gamma Exposures Due to Radionuclides Deposited in Urban Environments. Part I: Kerma Rates from Contaminated Urban Surfaces, Radiation Protection Dosimetry, Vol. 25, No. 3 (1988A) 167–180.

[4] MECKBACH, R., JACOB, P., Gamma Exposures Due to Radionuclides Deposited in Urban Environments. Part II: Location Factors for Different Deposition Patterns, Radiation Protection Dosimetry, Vol. 25, No. 3 (1988B) 181–190.

[5] PIRES DO RIO, M.A., Ressuspensão e Disseminação de ^{137}Cs em Áreas Urbanas: a experiência de Goiânia, Tese de Mestrado, Instituto de Biofísica carlos Chagas Filho, UFRJ (1993).

PUBLIC MONITORING DURING THE RADIOLOGICAL ACCIDENT IN GOIÂNIA

W.M. FERREIRA
Comissão Nacional de Energia Nuclear,
Distrito de Goiânia — DIGOI,
Goiânia, Goiás, Brazil

Abstract

PUBLIC MONITORING DURING THE RADIOLOGICAL ACCIDENT IN GOIÂNIA (BRAZIL).

During the radiological accident with Cs^{137} occurred at Goiânia, Brazil, many people were contaminated. To identify the people with possible contamination a large place in the center of the city was selected for screening people with a possibility of contamination. This paper describes the work involved monitoring about 112.800 persons in a period of three month.

1. INTRODUCTION

In 29th of September 1987 a robbery of teletherapy unit which contains a Cs^{137} source (19 grams of Caesium chloride), which belonged to the Radiotherapy Institute of Goiânia (IGR), generates one of the most serious radiological accidents in the world.

The rate of contamination was augmented due to the time period between starting of the accident and the notification by the authorities (16 days).

The source was a chemical compound of high solubility and its inadequate handling contributed to increase the number of contaminated people and places.

The interval between the robbery of the Cs source (13/09/1987) and the identification of the accident (29/09/1987) contribute to the scattering of the radiation of the Cs-source.

The people who manipulate the source, without knowing its dangerousness, were member of the same family with low level of education. They thought that the material which they found was a valuable one and could have a good commercial value. So they circulate fragments of this source among them, contaminating their residences and adjacent areas.

The contact between them and the other people increased significantly the number of contaminated people.

Part of this people were already evaluated clinically and interned in the Tropical Diseases Hospital (HDT), with a suspicion of intoxication.

After the verification of the accident (29/09/1987), and communication of the authorities of the State of Goiás about the robbery of the source, the search for other persons involved in the accident started.

At the end of this day, the governor of the State of Goiás and his assistants designed a civil defence unit together with the military police. They started searching for an area in the center of the city with an adequate infrastructure and an easy access for the people, to isolate the contaminated ones and establish a control point to monitor whole the population.

The Olympic Stadium was chosen as a place which offers the ideal conditions for that. Twenty six persons were identified initially, they were removed from their residences and isolated in eight tents.

In the day 30/10/1987, the National Atomic Energy Commission designated a screening team of 15 technicians for monitoring the population.

With this team, also integrated by social assistants from the State of Goiás to work in registering and orienting the people involved, searching for elimination of the panic and the uneasiness of the population which are supposed to be in the Olympic Stadium to monitored and rightly oriented about the accident.

The function of this team was to trace systematically the higher rates of the exposition to the natural radiation. Its principal objectives were : a) to monitor all the people who showed up in the stadium; b) in the case of a confirmed contamination, the person was registered and then his house together with the adjacent were investigated; c)applying the preliminary measurements of decontamination and the evaluation of the efficiency of the procedure; d) direct the contaminated people to an immediate medical care; e)establishing a dialogue with the contaminated persons, searching his social contacts for further radiometric investigation around his residence; f) evacuate any person from the contaminated areas and registering them with the help of social assistance for possible future compensation of their material losses; g) classification and collection of waste coming from contaminated areas; h) monitoring of vehicles that had been in the contaminated areas; i) verification with the involved person directly with the accident, if there is any materials from the contaminated area had been commercialised, since the materials have been passed in the junkers; j) installation of special telephone lines so as to facilitate the receiving of any associated information about the contamination accident.

2. METHODOLOGY

The establishment of the control point has permitted the monitoring team to adopt an adequate monitoring method.

Utilisation of high sensitive scintillation detectors (the very detectors used for uranium exploration), the people who stand in lines are separately monitored. In case of the detection of any contamination, the person is directed to a new monitoring point, well distant and well isolated form the rest of the people, such a place possess the background in the stadium.

The positively contaminated person, is asked to take off clothes so as to differentiate if the contamination is the clothes or the body. In case the contamination is due to the clothes or objects, these belongings are collected as waste and the involved are registered and above precede (shown above) are followed. On the other hand if the contamination is within the body, the person is subjected to preliminary medical decontaminating procedures such as bathing with water and neutral soap and later is directed to a specialist medical treatment.

The registration which have been collected from the contaminated person includes the identification of residence and working addresses, social contacts, daily habits, immediate parents, etc. These informations are passed to the technical staff that is monitoring the areas, persons, residences, and adjacent areas where the contaminated person were living. Consequently, these information used by the technical staff to carry further monitoring missions of special telephone lines so as to facilitate the receiving of any associated information about the contamination accident. In case of any telephone call, the monitoring team move directly to the area to carry out radiometric survey.

Another of the efficient method for spotting possible contaminated areas is to establish a dialogue with the population during the monitoring process. During the monitoring process, we carry an informal questionnaire about if they knew any further information. This led to the discovery of various contaminated areas. During our monitoring tours, we usually leave the detector switched (adjusted to beep out whenever the signal is above the permitted background limit). This allows the indication of any contaminated areas in the public high-ways.

3. RESULTS

The above methods have detected 35 contaminating homes in the city Goiânia and further 10 homes in the neighbouring cities. Eight homes have been crushed out and the rests are decontaminated.

In the public highways, forty five points have been detected and decontaminated.

All in all 112800 persons have been monitored in the Olympic Stadium, from which 249 persons have been contaminated. From these number of persons, 120 were decontaminated and set free. 79 persons have been exposed only externally and have been subjected to first aid medical service with no need for further hospitalisation. Fifty person with an internal contamination have been identified. Thirty of which have been partially isolated and twenty are subjected to hospital care.

4. CONCLUSIONS AND RECOMENDATIONS

The realised work, although with minimum infra-structure, permit the monitoring a grand part of the population, with a satisfactory results. From our experience, we recommended that in case of such radiological incident, one must not only take care of the technical side but also the psychological aspects of the population. In that direction, the dialogue which we established with the population had permitted the minimisation of the panic scattered by the mass media. It would have been much better if a group of specialised psychologist had been accompanying the technical services involved in monitoring the population.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, The radiological Accident in Goiânia, Vienna (1988).

[2] NAZARE ALVES, R., The radiological accident in Goiânia: preliminary report, presented to the Board of Governors of the IAEA, February (1988).

HOW THE RADIOLOGICAL ACCIDENT OF GOIÂNIA WAS INITIALLY DETERMINED

W. M. FERREIRA
Comissão Nacional de Energia Nuclear,
Distrito de Goiânia — DIGOI,
Goiânia, Goiás

Abstract

HOW THE RADIOLOGICAL ACCIDENT OF GOIÂNIA WAS INITIALLY DETERMINED.

Mainly the initial actions adopted to minimise the consequences of radiological accident involving the public are very important for bringing the situation to the normality. In this work the author presents a short history about the radiological accident with a ^{137}Cs source occurred in the city o Goiânia, Brazil in 1987 as well as the actions adopted by him during the first hours after the detection of the accident.

1. INTRODUCTION

The radiological accident, occurred in September 1987 in the city of Goiânia, Brazil, was generated by the robbery of a teletherapy unit containing a ^{137}Cs source. This unit belonged to the Instituto Goiáno de Radioterapia – IGR and this fact showed to the world the severe consequences of an accident with radioactive sources, mainly, when the population is directly involved. The contamination of large areas in the city, economical damages and loss of lives pointed out the complexity of the accident.

The accident started when the Instituto Goiáno de Radioterapia moved to a new address, leaving the ^{137}Cs source completely abandoned, without any security measures. The owners of the clinic had not given any notification to the competent authorities.

This paper describes the original version of the history of the accident, which was detected and revealed by the author on 29 September, 1987.

2. DESCRIPTION OF THE ACCIDENT

On September 29, 1987, at 08:00, I received a call from Dr. J. P. from the Fundação Estadual do Meio Ambiente – FEMAGO (State Environmental Protection Foundation), who requested some information about ionising radiation. He related that a friend of him, Dr. A. M., from the Hospital de Doenças Tropicais – HDT (Tropical Diseases Hospital) was investigating some cases of intoxication in persons, for which he was not able to define a diagnostic.

I contacted Dr. A. M., by telephone, to discuss his doubts he had about the effect of radiation. Dr. A. M., described that he had some patients which presented fever, diarrhoea, vomit, depilation and he could not establish a proper diagnostic. He asked if people submitted to radiation could present such symptoms. I told him that such symptoms where characteristics for acute radiation syndrome, but I could not believe that the State of Goi<s had radioactive material that could generate such a situation.

Dr. A. M., describing the patients which had been interned with the above symptoms, suspected already that a metallic "cylindrical piece" that was left in the State Sanitary Department for investigation by G.S. and M.F.I. would be the main reason for the intoxication of those persons.

He suggested to get in contact with Dr. P. M., veterinary and head of the Inspection and Analysis Section of the Sanitary Department who had received the "piece" on September 28, for more information about the piece.

After my first contact with Dr. P. M., I told him that I would borrow from Nuclebrás, a Brazilian uranium prospecting company, a detector to perform a survey measurement. The detector, a very sensitive scintilometer, indicated full scale 50 meters from the place were the "cylinder" was. In order to confirm this unbelievable fact, I got a second scintilometer which confirmed my finding.

During the time interval between the first and the second measurement, the fireman people were called to take the "piece" from that place and throw it in a river named Capim Puba, from were the water for the City of Goiânia is taken, in order to definitively solve the problem.

I convinced the firemen not to perform the action informing them that that material was radioactive and could not be charged in that way. I requested to the Sanitary Department that the workers should immediately get out of that place and, with the help of the fireman should isolate the area and maintaining it under permanent control.

The same day at 12:00, I received the information from Dr. P. M. that the piece came from a certain junkyard, where I found a large area in its vicinity contaminated. Later Miss. M. G. I. who lived in the junkyard confirmed that the piece was taken form the IGR and sold by the scavengers W. M. and R. A. S. to her husband, D.A.F.

I contacted the medical responsible for the IGR and they stated that they had transferred a ^{60}Co source to a new installation and left a ^{137}Cs source in the old clinic, without notifying the National Atomic Energy Commission (Comissão Nacional de Energia Nuclear (CNEN)). I informed them that the Caesium source had been robbed.

Dr. C.F. B. one of the responsible by the IGR have not believed ion what had happened. I requested from him the manual of the ^{137}Cs source in order to verify its characteristics. He said that he had no more the manuals. I went to the old clinic where, trough a survey measurement, I could verify that the source had not been not violated in that place.

Due to the severity of the situation, I went to the Health Secretary to inform the authorities about the occurrence. The people in the Secretary did not believed, at the beginning, in what I explained to them. After some resistance they allowed me to speak to the head of the Health Secretary, to whom I related what had occurred and the necessity to communicate the facts, immediately, to the competent authorities, CNEN located in Rio de Janeiro.

On 15:00, the Nuclear Installations Department from CNEN was informed about the disappearance of ^{137}Cs source.

Until this moment, the population had no knowledge about the severity of the situation. The actions which were started after this moment, in co-operation with the local authorities, were:

- Notify the Governor of the State of Goi<s (it was done by the head of the Health Secretary)

- Call the Civil Defence (fireman, military police) to isolate the contaminated areas.
- Hospitals and ambulances would be used following the necessities.
- The selection of a large place, located in the center of the city to screen contaminated persons.

The place that offered the best conditions was a Soccer Stadium, the Estádio Olímpico, located in the center area of the city. Together with the Health Secretary and using a Geiger-Müller detector from the I.G.R. were isolated; Junkyard I, sited at Rua 26-A; Junkyard II (where the child L.N.F. lived) on Rua 06, Setor Norte Ferroviário and the house of E. F., where part of the source was taken and thrown in a cesspool.

All the people from these places were conducted to the Estádio Olímpico and isolated in tends mounted by the Civil Defence. Until 22:00, twenty and two contaminated persons had been identified and isolated in this place.

On 00:30 of September 30. 1987, the Director of the Nuclear Installations Department of CNEN, Dr. J. J. R. assisted of two persons from the Instituto de Pesquisas Energeticas e Nucleares – IPEN, located in São Paulo, assumed the command of the operations.

On 07:00 of the same day, the 57 street, located in the central sector of Goiânia, where the source was opened, was isolated and the resident people evacuated and on 09:00 the same happened in the Junkyard II, located on P-19 street, Setor dos Funcionários.

3. SUGGESTIONS AND CONCLUSIONS

The radiological accident of Goiânia can be divided, during its initial phase, in two steps:

1) Accident confirmation phase.
2) Decisions phase.

When I was called by Dr. J. P. and the medical doctor Dr. A. M., I could not believe that a region located far from the industrial centres of the Country, where the concentration of radioactive sources is higher, would have an amount of radioactive material sufficient to generate an accident irradiating and contaminating a large number of persons.

Due to my friendship with Dr. J. P., I decided to investigate the denunciation, expecting not to find any trace of radioactive material, in special as was described, one "piece" 23 kilos weight that was deposited on a chair in the State Sanitary Vigilance.

The initial measurements performed with the scintilometer could not be quantified. However the determination to evacuate the Sanitary Vigilance was not well accepted due to the lack of knowledge about "radiation" regarding the local workers.

Which criteria should be adopted to isolate the areas? I have used occupational limits based on international standards for workers, even knowing that in an accident these values are not applicable but could be justified when persons from the public are involved.

However, the suggestions related below, are derived from the self experience of the author and the lesson experienced in the accident allow to present them:

(1) Always to fully investigate a denunciation;
(2) Immediately evaluate the occurrence;
(3) Never don't believe on your detector;
(4) Even working alone in a mission, the initial actions can save lives and minimise any tragedy;
(5) Good sense and fast action is very important for the control of the abnormal situation;
(6) To learn to work with the media, adopting a frank dialogue, explaining the occurrence in a comprehensive and clear language for the population;
(7) Suffering pressure from the authorities, remember that the protection of the population is the base of your work;
(8) You must do your work as the "abnormality controller" without worrying about any detail, even with the established panic;
(9) Re-evaluate always your action since the scenarios are, sometimes, mutable;
(10) The relevant information and observations are generated by your own action.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological Accident in Goiânia, Vienna (1988).

XA0054907

THE FOLLOW-UP OF IN VIVO MEASUREMENTS ON THE PATIENTS OF THE GOIÂNIA ACCIDENT

C.A.N. OLIVEIRA, D.R. MELO, B.M. DANTAS, G.J. NANI, J.L. LIPSZTEIN
Instituto de Radioproteção e Dosimetria,
Rio de Janeiro, Brazil

G.R. LAURER
Institute of Environmental Medicine,
New York University Medical Center,
Tuxedo, New York,
United States of America

Abstract

THE FOLLOW UP *OF* IN VIVO MEASUREMENTS ON THE PATIENTS OF THE GOIÂNIA ACCIDENT.

A radiological accident occurred in September 1987 in the city of Goiânia, Brazil, due to violation of a 50.9 TBq ^{137}Cs source used for medical therapy. This accident resulted internal and external contamination as well as irradiation of members of the public. Some people had radiation burns after rubbing the fragments of the source on their skin. Successive skin decontamination were carried on until there was no external detection of *\$* radiation. In August 1990, with the objective of verifying the long term retention of Cs in the scares, a detection system to perform *in vivo* measurements in specific regions of the body, with enough sensitivity to discriminate surface and deep contamination, based on the ratio K_α / K_β (^{137m}Ba characteristic X-rays) was set up in Goiânia. This system was also used to obtain information of the distribution of residual activities of ^{137}Cs in the body, 3 years after the intake. The detector applied in this set of measurements system consisted of a HPGe type N, collimated with a 20 cm x 0.5 mm layer of cooper. Ten people were selected for this study based on their remaining ^{137}Cs body burden, which was obtained using a 8"x4" NaI(Tl) detector, and on the presence of radiation burn scares. The selected individuals laid down on a thin matrix under the detection system. The HPGe was positioned over and close to the region of interest, which was different for each patient. Two of the subjects showed evidence of significant caesium activity still remaining in wound sites. These results were obtained through the detection of the ^{137m}Ba characteristic X-rays from the decay of ^{137}Cs. Four of the 10 individuals measured exhibited high levels of X-ray activity in the surface area above the liver. The measurement of these low energy X-rays (30 keV) from an organ as deep in the body as the liver indicates a significant amount of activity in that organ and also that caesium is probably not homogeneously distributed.

1. INTRODUCTION

During the early phase of the Goiânia accident, portable instruments (Geiger Mηller and scintillation detectors) were used to measure external contamination on the skin(1). It was observed that the measurements performed over areas of radiation burns showed higher counting rates than in other regions of the body, indicating the presence of ^{137}Cs in the wounds. After those measurements, successive skin decontamination were carried on, until there was no detectable beta radiation, which was the parameter adopted to indicate the absence of external contamination. However, the fact that radiation was not detected did not mean that the wounds were free of contamination. Some of the results could have indicated absence of contamination due to the low sensitivity of the detectors used in that early measurement phase, or as a consequence of caesium migration from the surface to deeper sites in the skin. Moreover, since the vascularization of the scar tissues is lower than of normal tissues[2], there was also the possibility of a different behaviour of the caesium in that tissue.

To verify the long-term retention of caesium in the scarred tissue, a detection system was assembled to perform *in vivo* measurements in specific regions of the body, with sufficient sensitivity to discriminate surface from deeper contamination, based on the ratio K_α and K_β of the ^{137m}Ba characteristic X-rays. This system was also used to obtain information on the distribution of the residual activities of the ^{137}Cs in the body 3 years after the intake.

2. MATERIALS AND METHODS

The measurements were performed in two steps:

1) The subjects were measured in the whole-body counting position (a modified meter-arc) for the estimation of total ^{137}Cs, using the 20 cm diameter x 10 cm-thick NaI(Tl) detector[3]. The counting time for this measurement was dependent on the activity still present in the body 3 years after the accident.
2) The subjects laid on a thin plastic matrix under the detection system, with the HPGe detector positioned over and close to the area of interest on the body, which was different for each patient. The detection system consisted of a high purity germanium detector (HPGe), type N, supplier Intertechnique, collimated with a 10 cm (wide) x 0.5 mm (thick) layer of copper.

The evaluation of the measurements performed with the HPGe detector were based on the detection of the K_v and K_3 X-rays of ^{137m}Ba (32.07 and 36.68 keV, respectively). Depending on the scar caused by the radiation burns and on the activity still present, this measurement could last from 4 to 8 hours. For those cases when the counting time had to be very long, the measurements were completed with more than 1 day of counting. After each measurement, the spectra were stored on a disk, for later analysis.

3. RESULTS AND DISCUSSION

The measurements were done in 10 individuals that still had measurable ^{137}Cs body burdens 3 years after intake. Two people have shown significant activities at the cicatrised skin tissues. One of them had a cicatrix on the inside surface of his right leg, near the knee. The activities measured were just slightly above the detection limits for the K_α and K_β X-rays of ^{137m}Ba. The other individual had a severe burn in his right thigh. The results show that significant amount of activity remain retained in such location.

Measurements to obtain information on the distribution of the caesium in the body were also performed, using the HPGe detection system. A woman, who had a very high internal contamination (calculated intake of 300 MBq) has shown a higher concentration in the region of liver than in other regions of the body. Results are shown in Fig. 1. The X-ray counting rates, as detected using the NaI(Tl) crystal, shows an apparent higher concentration of ^{137}Cs in the right kidney in relation to the left kidney. This result is probably due to the influence of the high caesium activity in the liver, since the liver and the right kidney are located in the same region of the body. This hypothesis is confirmed through the measurements of ^{137m}Ba characteristic X-rays, K_α and K_β which have shown similar counting rates on both kidneys. The high counting rates over the liver were observed in 4 individuals. The detection of contamination in the liver is in agreement with the findings of Rosoff *et al.*[4] on the presence of significant ^{137}Cs activities in this organ, in a study involving the distribution of caesium *post mortem* in several organs and tissues of the human body. Melo *et al.*[5] in an experiment involving the administration of ^{137}Cs to beagle dogs, have observed that

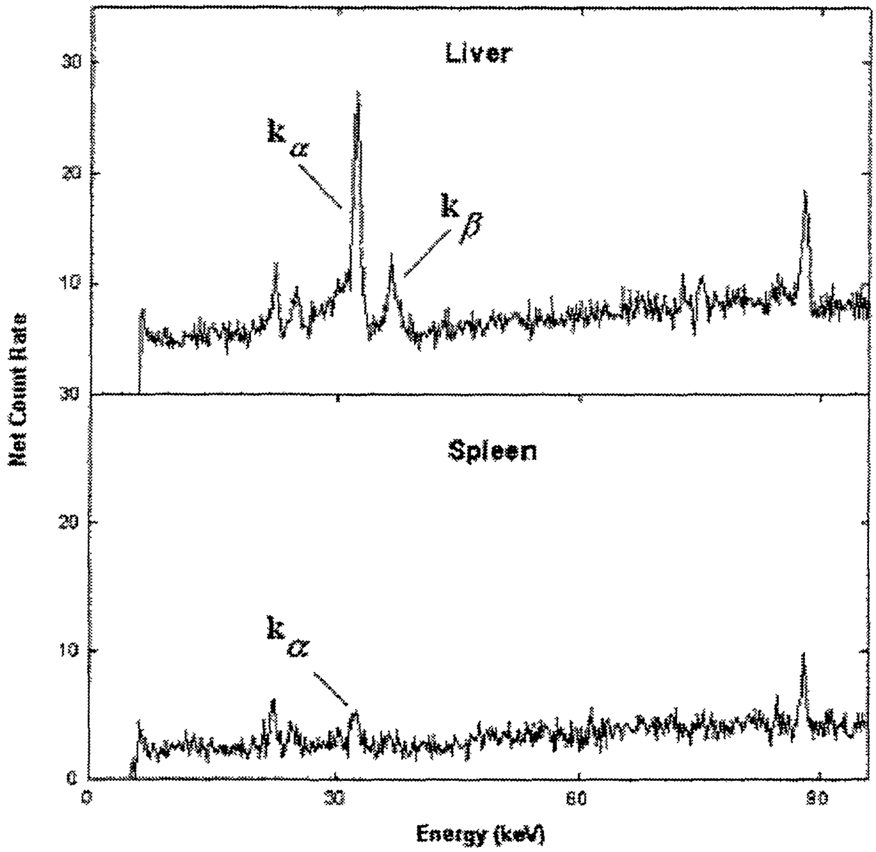


FIG. 1. Spectra of the measurement of one subject with the HPGe detector positioned over the liver and spleen

among all tissues, the highest caesium concentration were located in the skeletal muscle tissue, liver, spleen and kidney.

In order to avoid the interference of bone attenuation in the detection of the ^{137m}Ba characteristic X-rays, the measurements made over the liver, kidneys and spleen were performed with the detector positioned in the region bellow the last rib. The measurements were made on both sides of the body (right and left) considering the umbilicus as the center point. Kidneys measurements were performed with the person lying on supine position and liver and spleen measurements were done on frontal position.

4. CONCLUSIONS

The scar measurements were not clear to determine the depth of the contamination in the wound sites. This is probably due to a different rate of clearance from the scar tissue, than from the rest of the body. The long biological half-time in scar tissue implies a larger radiation dose delivered to the surrounding healthy tissues.

The observation of high counting rates over the liver of 4 subjects is very important. The detection of these relatively low energy photons from an organ as deep as the liver indicates that a significant amount of activity resides within that organ of these subjects and that the distribution of ^{137}Cs in the body may not always be considered homogeneous.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Rapid Monitoring of a Large Group of Internally Contaminated People Following a Radiation Accident, IAEA–TECDOC–746, Vienna, (1994).

[2] OLIVEIRA, A.R., MELLO, C.E.B., VALVERDE, N.J.L., FARINA, R., CURADO, M.P., Localised Lesions Induced by ^{137}Cs During the Goiânia Accident, Health Phys. **60** 1 (1991a) 25–29.

[3] OLIVEIRA, C.A.N., LOURENÇO, M.C., DANTAS, B.M., LUCENA, E.A., Design and Operation of a Whole Body Monitoring System for the Goiânia Radiation Accident, Health Phys. **60** 1 (1991b) 51–55.

[4] ROSOFF, B., COHN, S.H., SPENCER, H., Caesium-137 Metabolism in Man, Radiation. Research **19** (1963) 643–654.

[5] MELO, D.R., LUNDGREN, D.L., MUGGENBURG, B.A., GUILMETTE, R.A., Decorporation of ^{137}Cs in beagle dogs of different ages, Health Phys. **71** 2 (1996) 190–197.

MEDICAL FOLLOW-UP OF THE RADIATION ACCIDENT WITH ^{137}Cs IN GOIÂNIA — AN UPDATE (1990–1994)

C.E. BRANDÃO-MELLO, R. FARINA
CNEN – National Nuclear Energy Commission (NNEC),
Rio de Janeiro

A. RODRIGUES DE OLIVEIRA
INB – Brazilian Nuclear Industries,
Rio de Janeiro

M.P. CURADO, J.F. FILHO, Q.C.B. SANTOS
FUNLEIDE – Fundação Leide Das Neves Ferreira,
Goiânia

Brazil

Abstract

MEDICAL FOLLOW-UP OF THE RADIATION ACCIDENT WITH ^{137}Cs IN GOIÂNIA — AN UPDATE (1990–1994).

On September 13, 1987 a shielded ^{137}Cs source was removed by two scavengers from a teletherapy unit in abandoned clinic in Goiânia, Brazil, and was later broken open. The source was handled by many people from the time it was removed (Sept 13) until it was taken to the sanitary surveillance division (Sept 28).

Many of these people (approximately 250) were exposed to large external and internal doses of radiation from the radioactive source; of these, 50 showed signal and symptoms of whole-body irradiation and local acute irradiation and also showed signs of external or internal contamination from ingested or absorbed ^{137}Cs. Fourteen of those 50 developed moderate to severe bone marrow (BM) injury and required intensive medical care at a specialised unit in Rio de Janeiro. None were subjected to BM transplants. Ultimately, 4 of these casualties died of bleeding and sepsis despite the administration of GM–CSF (Granulocyte Macrophage Colony Stimulating Factor). Internal contamination due to ingestion or absorption of ^{137}Cs was successfully removed by means of administration of Prussian Blue at doses ranging from 1.5–10.0 gm/day. Radiation induced skin injuries were observed in 28 patients requiring surgical and post-operative procedures.

Since March 1988 a medical follow up protocol was established by NNEC and the Leide Das Neves Ferreira Foundation of the state of Goiás, in order to prospectively follow more than 150 victims. The aim of this paper is to describe the main after-effects of the ^{137}Cs accident in the last 4 years, giving emphasis on clinical, haematological, radiological and psychological aspects.

1. HEMATOLOGICAL ASPECTS

The critical phase of the acute radiation syndrome (ARS) in Goiânia was characterised by haematological injury. Fourteen of the 50 severely injured patients developed bone marrow depression; and eight of them had such classical signs and symptoms of the ARS. Four of them died due to bleeding diathesis and infection (sepsis) caused by Klebsiella resistant to antibiotics and vasopressors. To none of them it was recommended to submit to a bone marrow transplant.

Since February 1988 the most severely exposed victims (57) have been examined quarterly with blood counts, platelet counts, and retyculocytes. Bone marrow aspirate and biopsy were done yearly. From the haematological point of view all but 4 patients have normal blood cell counts. These 4 patients have mild and transient leukopenia and no clinical and infectious complications. Bone marrow aspirate and biopsy show normality in all but 3 patients, in which a striking eosinophilia was observed.

Bone marrow aspirate and smears are being collected for cytogenetical purposes, looking for mutation and oncogene markers and chromosomal aberrations.

2. RADIATION SKIN INJURIES

Radiation induced skin injuries were observed in 28 patients who had handled the source housing or fragments of the source itself.

Victims who handled the container received gamma radiation partly attenuated by the protective shielding material. Localised injuries caused by beta plus gamma radiation were observed in those who handled the unshielded source. Various parts of their bodies, including oral mucosa, had been in direct contact with the radioactive material. Local symptoms appeared a few hours after contact between the source and the skin surface. Pain, sensation of local heat, burning and pruritus, as well as changes in sensitivity were the most frequent complaints.

After the period of latency, a second wave of localised disturbances appeared, characterising the critical phase, which was represented by secondary erithema, resembling a normal thermal burn. Soon afterwards, blisters or bullae developed, followed by rupture and drainage. Then a skin regeneration process began, characterised by tissue granulation at the outer edges of the injury, progressing toward the middle.

In six cases, significant ulceration developed after rapid period of erithema and blistering, and there was no latency phase. For the majority of patients, the injuries evolved favourably with complete or nearly complete, recovery within a few months after the accident.

Initially, the radiation skin injuries were managed conservatively by topical applications of anti-septic, anti-inflammatory and analgesic solutions, antibiotic creams (Neomycin) and creams containing substances with anti prostaglandin-like effects and anti-inflammatory actions (Aloe Vera, Allantoin).

The follow-up treatment was continued for patients having only desquamative epithelitis, superficial ulcers or local reactions of an inflammatory nature.

Twelve of the 28 victims had multiple injuries, affecting predominantly the upper limbs.

Scars remained in eighteen patients after the critical phase of the accident and were managed with topical conservative measure.

Injuries did not heal completely and relapsed in 8 patients, who then required surgical debridments, amputation of the digital extremities and plastic skin grafts.

A prospective follow up protocol of the skin radiation injuries is currently underway including angioscintillography with ^{99m}Tc, electromiography and CT scans in order to evaluate, identify and prevent relapses.

Recently one severely irradiated patient developed upon lower limbs a malignant skin lesion morphologically classified as a lentigo which was surgically excised.

Electromiography has been used to evaluate parenthetic abnormalities, hiperesthesia, hipoesthesia, tingling and pruritus, with good results.

A clear limitation of the flexion (ankilosis) in the proximal and distant phalanxes of the finger and toes was experienced by 4 (four) patients due to fibrosis and tissue atrophy. Exercises and kinetic manoeuvres are being encouraged.

3. CLINICAL ASPECTS — (UPDATE 1990–1994)

From the clinical and haematological point of view, the great majority of the patients were in good health during the last 4 years.

Gastrointestinal complaints, such as heartburn, dyspepsia and nausea were relatively common.

Upper G.I. tract endoscopy was done in a significant number of patients, which revealed chronic gastritis, peptic ulcer, esophagitis, related directly or not to Helycobacter pillories. Adequate treatment was done with anti-acids, H_2 blockers, Metronidazole, diet and psychotherapy support. At the same time stools were analysed for ova and parasites and revealed intestinal parasites such as giardia lamblia, entamoeba histolytic and strongyloides stercoralis. These diseases are not radiation induced; they are not different from those present among the general population in Brazil. It must be borne in mind that the majority of the victims come from a very low socio-economic and cultural stratum of the local population. Most of them are heavy smokers, consume high doses of alcohol and eat fatty seasoned food.

Recently (1993) one of the most severely exposed patient (7.0 Gy) developed a chronic liver failure characterised by ascitis, jaundice, GI tract bleeding and malaise. He was admitted to the hospital and underwent a liver percutaneous biopsy which displayed alcoholic liver disease. In last May, 1994 he was readmitted to the hospital with signs and symptoms of chronic liver failure, such as jaundice, ascitis, encephalopathy and upper gastrointestinal bleeding (melena). He developed hepato-renal syndrome, acute respiratory distress and died. Autopsy was done.

Cardiovascular abnormalities are mainly represented by moderate to light hypertension treated with diuretics and betablockers.

The male population that incurred in high doses of irradiation (more than 1.0 Gy) are oligospermic or azoospermic.

The female population displayed commonly gynaecological infections due to candida and trichomonas.

At the beginning of 1992, a 32 year old woman, who had received (1.0 Gray) of external exposure and a very high internal body burden (4×10^8 Bq), delivered a male baby with good health. Blood counts, cytogenetic dosimetry and total body counting were performed and no significant internal contamination was noted.

Very recently two patients who incurred external doses lower than 0.2 Gy died, one of them due to complications of Chagas disease (megacolon and megaesophagus) accelerated by bacterial infection (E. coli) and the other due to breast cancer. Both of them were not internally contaminated.

4. PSYCHOLOGICAL ASPECTS

During the four months the patients were hospitalised at Goiânia and Rio de Janeiro, a number of curious and unusual psychological reactions occurred. The major psychological and psychoneurotic after-effects of the 20 more severely exposed patients are summarised elsewhere (5). These data were recently published and presented at the III Medical Basis for Radiation Accident Preparedness. — The Psychological Perspective, held from 5–7 Dec 1990, in Oak Ridge, TN, USA. Of the 20 patients, 14 developed depression because of the prolonged confinement or because of the stress resulting from the accident itself. As the confinement became more oppressive, anxiety, irritability and emotional liability increased. Others displayed insomnia, nightmares and unexpected reactions to the news from the media.

Nowadays, the patients are at the stage of the delayed effects. This period is basically represented by the difficult adaptation to a new mode of life and work, by negative attitudes about the sufficiency and equity of social assistance, and the desire to be compensated by the state and receive secondary benefits.

Two patients, in particular, previously diagnosed as having psychotic syndromes, are still under close surveillance with psychiatrists and psychologists. Carbamazepine, Haloperidol, Amplictil and Phenytoin are being prescribed for those cases. Very recently one of them was once more admitted to a psychiatric hospital and experienced a reactivation of the psychotic syndrome.

REFERENCES

[1] BRANDÃO MELLO, C.E., et al., The Clinical and Haematological Aspects of ^{137}Cs: The Goiânia Radiation Accident, Health Physics Journal, **60** 1 January (1991).

[2] OLIVEIRA, A.R., et al., Localised lesions induced by ^{137}Cs during the Goiânia Accident, Health Physics Journal. January, **60** 1 (1991).

[3] OLIVEIRA, A.R., et al., Medical and related aspects of the Goiânia Accident: An Overview, Health Physics Journal, **60** 1 January (1991).

[4] FARINA, R., et al., Medical Aspects of ^{137}Cs Decorporation: The Goiânia Radiological Accident, Health Physics Journal, **60** 1 January (1991).

[5] BRANDÃO MELLO, C.E., et al., The Psychological Effects of the Goiânia Radiation Accident on the Hospitalised Victims. The Medical Basis for Radiation Accident Preparedness. The Psychological Perspective, (RICK, R., BERGER, M.E., O'HARA, F.M., Eds.), Elsevier Science Publishing Co., Inc., New York, NY (1991).

[6] BRANDÃO MELLO, C.E., Personal Insights on the Goiânia Radiation Accident, Health Physics Journal, **60** 1 January (1991).

PSYCHOSOCIAL ASPECTS OF THE VICTIMS OF THE ACCIDENT WITH CAESIUM-137 IN GOIÂNIA (1987–1994)

M.P. CURADO
Fundação Leide das Neves Ferreira,
Goiás

S.B. COSTA NETO
Universidade de Brasília,
Instituto de Psicologia,
Rio de Janeiro

Brazil

Abstract

PSYCHOSOCIAL ASPECTS OF THE VICTIMS OF THE ACCIDENT WITH CAESIUM-137 IN GOIÂNIA (1987–1994).

In September of 1987 two men took possession of and violated a source containing Caesium-137, which caused the Radiological Accident of Goiânia. Besides the direct victims, a significant part of the community of Goiânia was directly involved with this accident.

The psychosocial impact in the social groups involved in this radiological accident — the population as a whole, immediate neighbours of contaminated sites, professionals and the victims themselves — gave rise to specific behaviour and attitudes which will be discussed in this paper.

1. THE POPULATION

The expected physical and psychological symptoms associated with cases of exposure to and/or contamination by radioactive material were present in five thousand, out of the 112 thousand people under monitoring at the Olympic Stadium, representing 10% of the population of Goiânia. Among them we observed nausea, vomiting, skin lesions and other psychoactive alterations which, at that time, were credited to the impact, on the population, of the perception of risk involved. These symptoms were aggravated as news of the accident and its consequences on the human body began to occupy headlines of the principal newspaper and to deserve intensive TV coverage.

Thus, the feeling of anxiety, fear and insecurity which were prevalent in this community — often interpreted by the media as panic found somatic expression in the population.

Another fact that further proved the existence of the perception of risk by the population as a whole was the thousands of phone calls received by a special information service set up by the State Government. Volunteers manning these special telephone numbers would hear people from the community, give information and orient those who called about the accident. Many called asking for investigation on other possible contaminated sites which the technicians had not yet examined.

2. THE IMMEDIATE NEIGHBOURS OF CONTAMINATED SITES

The group of neighbours of contaminated sites is made up of people who lived or worked in a region located within a 300m radius of the nine main contaminated sites by the Caesium-137. This group is formed by, approximately, five thousand people. Many of them are targets for prejudiced behaviour as indirect victims of the accident. Discrimination to these people took several forms: from feelings of guilt to loss in real state value of their houses, even after it was proved that there had been no involvement in the accident.

When 333 neighbours of contaminated sites were approached (Curado, Costa Neto and Helou, 1990), 35 months after the accident, there still persisted a notion of risk which involved fear of developing physical (18.5%), and mental diseases (25.1%), fear of death (9%), of congenital malformation (14%), and of soil (13%), vegetal (10.2%), and water contaminated (.9%). For 10.4% of the population, there still existed the possibility that other accidents of this type could happen.

3. PROFESSIONALS AND VOLUNTEERS AT WORK

The objective of the group formed by professionals and volunteer workers was to assist the people involved in the accident and work in the decontamination of the affected areas. This group of workers, in spite of their technical activities, felt great empathy for the victims of the accident in Goiânia. Many suffered some degree of discrimination which resulted in moments of anxiety, depression, fear, irritation and occasional insomnia. Helou (1990), in a retrospective study dome with 123 of the professionals who had worked with the accident, observed, that among them, there had been changes in career (36.3%), in their emotional lives (22.6%), in social roles (11.6%) and even in identity factors (13.7%). Family relationships were among the factors which least suffered from the accident with the Caesium-137 (1%). Other studies about accidents and natural disasters which had take place in the Americas (Lima and Graviria, 1989) also concluded that there was a psychosocial involvement on the part of the professionals who came to the aid of the victims. There studies showed that the people involved in the post-accident activities asked for psychological and psychiatric help years after the catastrophes had taken place.

4. THE VICTIMS

The group is composed of 249 people who were exposed to or contaminated by the Caesium-137. One hundred and eighteen of these people became, initially, clients of the Leide das Neves Foundation – FUNLEIDE and receive a life pension from the Government of the State of Goiás.

The Foundation started to assist these victims in February of 1988. From September of 1987 to January of 1988 they manifested psychological disturbances which did not, necessarily, correspond, directly, to the degree of exposition and/or radioactive contamination. Psychological alteration such as anxiety, depression, low self-esteem, guilt, self-discrimination, aggressiveness and psychiatric alterations were treated with medication and psychotherapeutic procedures.

In a retrospective analysis of the subsequent phases in the behaviour of these victims (Helou, Cardoso and Costa Neto, 1983) it was observed that dizziness (stunning), confusion and astonishment were the principal psychological factors which appeared during the first stage (a stage of threat), that is, the period just before the official divulgation of the accident.

During the stage of shock there were periods of euphoria caused by survival, periods of hope, solidarity and even of mystical behaviour.

The period comprised between the creation of FUNLEIDE and the institution of the life pensions paid by the State Government marked he beginning of the stage of readaptation. During this stage the victims started to show a greater awareness of the medium and long term effects of the radiation. That factor contributed to the creation of the Victim's Association. During this period, increased consumption of alcohol and tobacco, as well as self-distracting and suicidal ideas were observed and this behaviour was not solely attributed to the effects of the ionising radiation.

We are presently at the sequel stage, which started with the donation of houses to the victims and the institution of life pensions. Constant thoughts of death as well as fear of the development of malignant neoplasm have been observed and in the last two years after the accident, we have noticed an increase of these feelings, as they were exacerbated by the death of four of the patients.

Besides the psychological disturbances, psychiatric alterations were observed in 17 of the patients affected by the radiation with doses equal to or greater than 1 Gy. Two of these patients received a combination treatment of psychotropic medication associated with psychotherapy sessions (Table I).

TABLE I. PATIENTS WITH RADIATION DOSES EQUAL TO OR GREATER THAN 1 GY UNDER PSYCHOLOGICAL AND/OR PSYCHIATRIC COUNSELLING AND USAGE OF PSYCHOTROPICS (1990).

Patients (N=7)	**Dose [Gy (rad)]**	**Psychotherapy Sessions**	**Psychiatric**	**Psychotropics**
GGS	2.9 (290)	40	Yes	Yes
DAF	7.0 (700)	18	Yes	Yes
RSA	6.2 (620)	03	Yes	Yes
LNF	1.3 (130)	02	No	No
EBS	2.9 (290)	01	No	No
IAF	3.0 (300)	60	No	No
OAF	1.0 (100)	01	No	No
EF	4.4 (440)	01	No	No
ErF	2.1 (210)	01	No	No
WMP	2.7 (270)	08	No	No
KSS	1.1 (110)	—	No	No
LOMS	1.0 (100)	06	No	No
MGA	4.3 (430)	08	No	No
OAFJ	1.6 (160)	02	No	No
DFF	1.2 (120)	02	No	No
PRM	1.3 (130)	0	No	No
RBG	1.1 (110)	04	No	No

SOURCE: CURADO, COSTA NETO and HELOU, S. (1990). Psychological Aspects of the Radiation Accident in Goiânia: A General Overview on Victims and Population. The Medical Basis for Radiation-Accident Preparedness III. New York: Elsevier Science Publishing Company, Inc.

From 1990 on, the victims who came regularly the psychotherapy sessions developed greater emotional stability.

The behaviour disturbances verified among the children were more noticeably expressed within the family relationships. However, none of the children presented any meaningful psychomotor difficulty or adjustment problems within their school environment.

The persistency of the psychological disturbances throughout this period of time demonstrates that the psychosocial factors are chronic and, not infrequently, difficult to solve (Costa Neto, 1994).

Some social factors should be considered as elements of influence in the behaviour of the victims, during the time elapsed between 1987 and 1993 (Santana, Leal and Prudente, 1993).

We will now briefly discuss three of these:

Material Losses: These varied between loss of real state, furniture and personal objects. It was the opinion of the victims that the compensation for these losses unsatisfactory, even though they are still receiving a life pension from the State Government.

Economic Losses: There were losses for the people who worked within the context of formal and informal economy as well as for those who did not have any economic activity. These losses were characterised by an increase in unemployment up to 1990. Beginning in 1991 the picture was inverted and up to 70% of the people involved in the accident started to work again, gradually, both in the formal and in the informal sectors of the economy.

Material losses and the low purchase power after the accident forced these people to move from the more central areas of the town to the suburbs. Some of the families which had lost their homes during the decontamination process have not still been able to legally reprocess them and this is another factor that generates insecurity among them.

Change in the social role: The relationships of the victims, formed, initially, by the family group and friends were temporarily restricted at the critical moment, due to the characteristics of the accident, but later on, the victims started to be treated by FUNLEIDE and by professionals of the institutions that were involved in the medium and long term follow up of the accident. The new role taken by the group after the accident was that of victims. The group organised itself in a **Victim's Association**. Led by a group involved with them, the victims restructured their social lives and were gradually able to move away from discrimination to a more open social life which included reflections on the consequences of the accident with the Caesium-137.

Because of these material, economic and affective losses these victims felt a great need of concrete guarantees form the State Government. The State Social Service is now the target office, and has suffered an increase in demand for its services.

5. DISCUSSION

The great initial challenge in the rehabilitation of these victims was to assist them and, at the same time, to promote a greater social awareness and independence for them. The policy adopted by the institution in the assistance of these victims has helped to perpetuate their role of victims.

We have also observed great difficulty, on their part, to adhere to the treatment offered by FUNLEIDE. Among the victims of the accident there is still a prevalent feeling of mistrust in relation to the institutions which are supposed to assist them and this feeling is responsible for constant complaints to the press about their competency. These victims also look for outside help, including in their competency. These victims also look for outside help, including in their search foreign institutions, as was the case with Cuba. However, Helou and Cardoso (1993) asked 35 of the adult victims to answer a questionnaire and 54% of them manifested their trust in the services offered to them by the institution responsible for their follow up.

The diagnosis of cancer among these victims of the radioactive accident has increased the tensions among the group and has generated feelings of insecurity.

The health team that sees the victims on a daily basis must be prepared to effectively deal with the possibility — even if minute — of cancer occurring among members of the group. All the people involved are very aware of this possibility. Shavelzon (1989) suggests that when someone is worried about a certain disease, this fact can lead to a situation of psychological stress which will promote bio-chemical alterations and, possibly, the onset of the fretted disease.

6. CONCLUSIONS

In an evaluation of the behaviour of the victims, we will find important points to consider:

- The psychology team should act on the accident since its onset through the use of individual and group counselling sessions. House visits are also recommended in order to reinforce the credibility of the emergency team;
- The social Service should try to rehabilitate and reintegrate the group in their new social context, from the onset of the emergency stage;
- The health team should decide on a follow up protocol and periodically re-evaluate the findings;
- The population which was exposed to the accident should be made ware of the possibility of developing cancer as a late sequel of the exposure to ionising radiation:
- Social and assistance interventions should be able to anticipate and control the possible secondary gains of the radiological accident.

The experience with the radiological accident of Goiânia has demonstrated that the psychosocial effects do not correspond linearly to the degree of physical involvement and the exposure to radioactive material.

REFERENCES

[1] COSTA NETO, S.B., Fatores do Processo de Tomada de Decisão de uma Equipe de Saúde numa Instituição de Tratamento a Irradiados por Fonte Ionizante: um estudo de caso, Dissertação de Mestrado, Brasília: Universidade de Brasília/CNPq (1994).

[2] HELOU, S., CARDOSO, H., Pesquisa de Opinião dos Radioacidentados de Goiânia sobre os Serviços Prestados pela Fundação Leide das Neves Ferreira, the text was not published, Goiânia: FUNLEIDE (1994).

[3] HELOU, S., CURADO, H.A., COSTA NETO, S.B., Fases Evolutivas de Comportamento no Acidente Radiológica de Goiânia, Annals do II Simpósio Internacional Sobre o Acidente Radioativo com Césio-137, Goiânia-Go, Brazil (1993).

[4] SANTANA, N.C., LEAL, S.R.A., PRUDENTE, M.C., Relatório Técnico do Serviço Social", Paper presented at the II Simpósio Internacional Sobre o Acidente Radioativo com Césio-137, Goiânia-Go, Brazil (1993).

[5] ANDRADE, G.S., et al., Serviço Social e o Acidente Radioativo de Goiânia. Lições do Acidente com Césio-137 em Goiânia, Goiânia.: Fundação Leide das Neves Ferreira e CNPq (1990).

[6] CURADO, M.P., COSTA NETO, S.B., HELOU, S., Psychological Aspects of the Radiation Accident in Goiânia: A General Overview on Victims and Population. The Medical Basis for Radiation-Accident Preparedness II,. New York, Elsevier Science Publishing Company, Inc. (1990).

[7] HELOU, S., Consequências Psicossociais do Acidente Radiológica de Goiânia, Goiânia, Universidade Federal de Goiás (no prelo) (1990).

[8] SHAVELZON, J., Lo Psicosocial en la Cancerologia, Annals of the I Encontro Brazileiro de Psico-concologia, Curitiba–PR, Brazil (1989).

[9] SHAVELZON, J., Un Modelo Psicosomático y Psicosocial. Annals of the I Encontro Brazileiro de Psico-concologia, Curitiba–PR, Brazil (1989).

XA0054910

THE SPREAD OF ^{137}CS BY RESUSPENSION OF CONTAMINATED SOIL IN THE URBAN AREA OF GOIÂNIA

M.A. PIRES DO RIO, E.C.S. AMARAL
CNEN—Instituto de Radioproteção e Dosimetria,
Rio de Janeiro, Brazil

H.G. PARETZKE
GSF—Institut für Strahlenschutz,
Neuherberg, Oberschleißheim,
Germany

Abstract

SPREADING OF ^{137}CS BY RESUSPENSION OF CONTAMINATED SOIL IN THE URBAN AREA OF GOIÂNIA.

Measurements regarding the population exposure were performed in Goiânia after the radiological accident as well as studies on resuspension and redeposition of ^{137}Cs in urban areas, on the contribution of soil splash to the ^{137}Cs uptake by leafy vegetables and on the transfer of ^{137}Cs from soil to chicken meat and eggs. Periodical street dust sampling was used to follow-up the spreading of the radionuclide in the city. The results do not indicate a measurable spreading of this radionuclide throughout the city from the contaminated areas, but resuspension can lead to significant local contamination of agricultural products, equipment, structures, etc.

1. INTRODUCTION

The accidental opening of a ^{137}Cs teletherapy unit at the city of Goiânia, Brazil, in September 1987, resulted in the irradiation and contamination of many inhabitants as well as of the surrounding environment; a restricted local secondary contamination by weather and human action occurred within an urban area of about 1 km^2 around the main foci of primary contamination (Figure 1) (IAEA, 1988; Health Physics, 1991). This situation allowed important studies on resuspension and redeposition processes of ^{137}Cs in an urban area under tropical climate conditions (Pires do Rio, 1993; Pires do Rio *et al.* 1994). Also performed were dose rate measurements and ^{137}Cs determination in vegetables cultivated in the garden as well as chicken meat and eggs from poultry that incidentally ingested contaminated soil (Amaral *et al.* 1992, 1994a). For these studies, a house at 57th street 80 m distant from focus 1, where the source was broken, was chosen for the experiments (Figure 2). Street dust samplings were used to follow-up the spreading of radionuclides from the contaminated area to other areas of the city.

2. MATERIAL AND METHODS

The following methodologies were adopted in the experiments:

a) Resuspension and redeposition studies: Air, total deposition, rain water and surface soil were sampled over two years at a front and backyard of the experimental house and analysed for ^{137}Cs. Standard EPA-type air samplers were used intermittently eight times per day for 20 minutes and the filters were measured after every 10 days. The total deposition was collected in stainless tubs (0.8 x 0.8 m^2, 0.3 m high walls) with a permanent water layer of 5 cm. After every 10 days the tubs were drained and the volume reduced by evaporation to 250

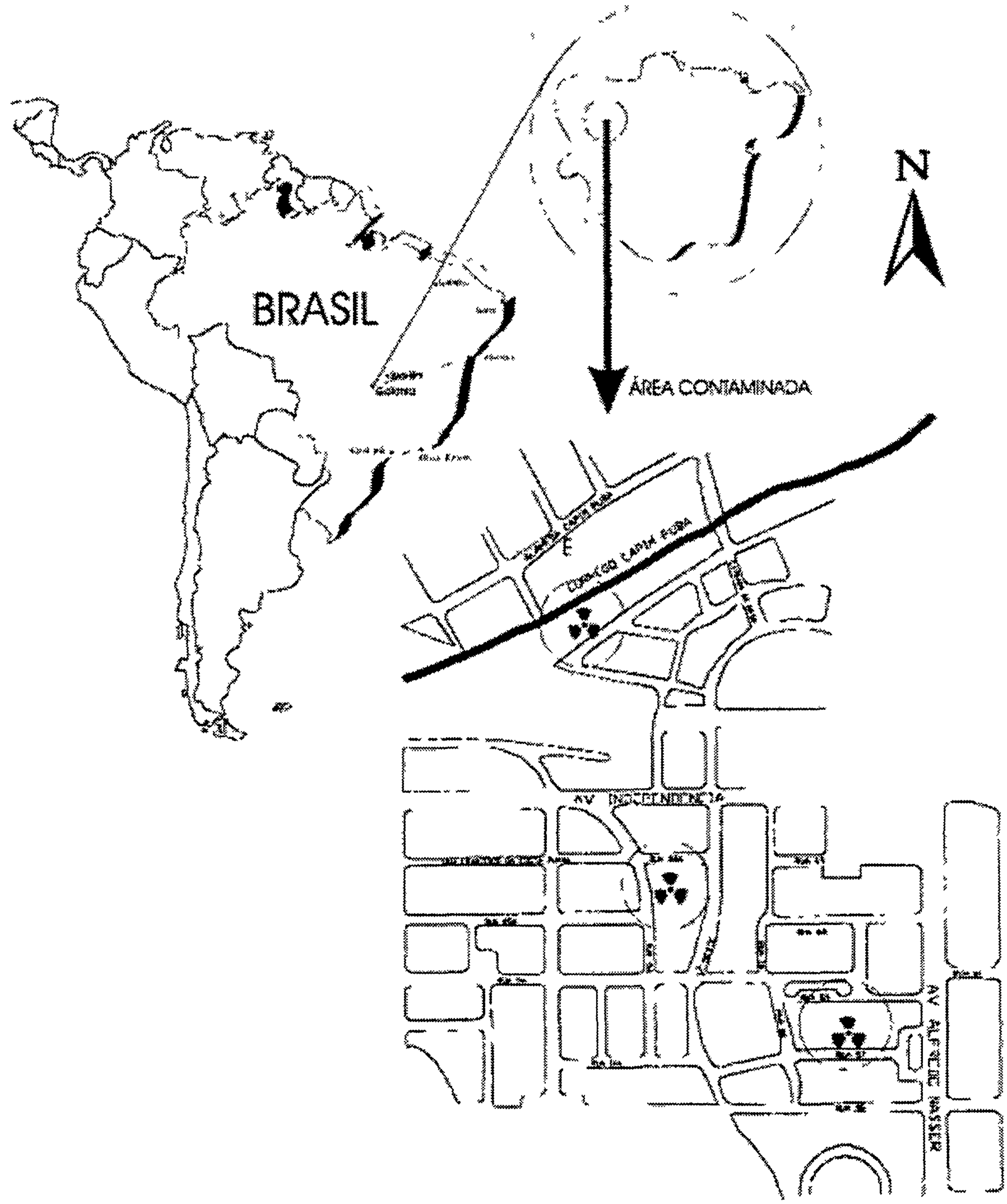


FIG.1. Location of Goiânia and of the main focus of contamination.

ml, prior to analysis. Periodically, surface soil was sampled at representative locations by pressing sticky paper (10 x 10 cm^2) directly on the soil and kept in individual plastic envelopes. Also was used a four stages high-volume cascade impactor with an inlet cut off of 15 µm to collect size differentiated aerosol samples. Taking the deposition pattern and the wind direction data into account, two grids of street dust sampling with a total area of 36 km^2 were established in the city. Periodical sampling were performed from May 1989 until August 1994. The samples were collected using a brush and kept in individual plastic bags (Pires do Rio, 1993; Pires do Rio *et al.*, 1994).

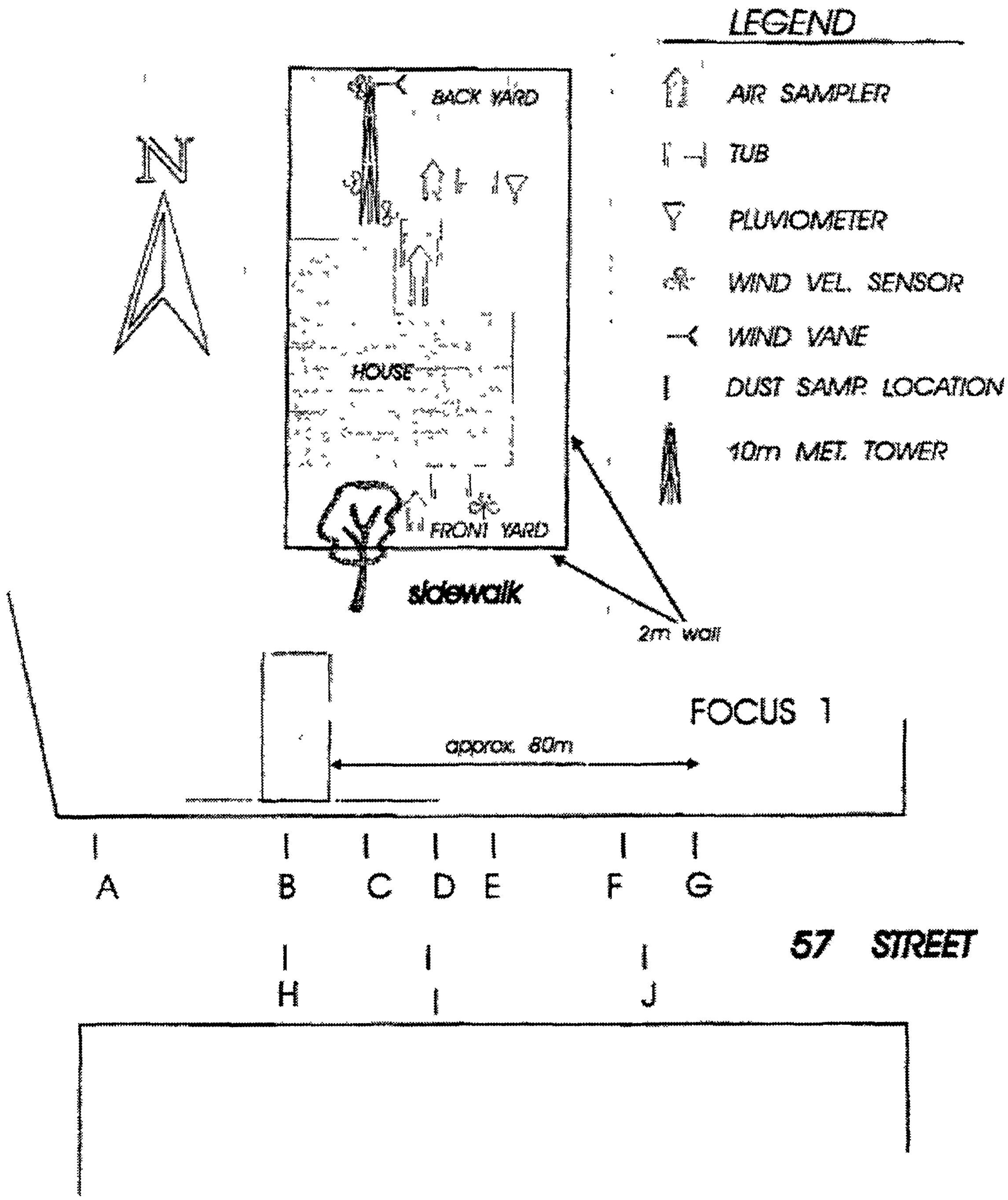


FIG. 2. House at 57th street used for the experiments.

b) Vegetables experiments: Three 90 cm x 80 cm areas in the vegetable garden were prepared for cultivation of lettuce and green cole and organic fertiliser was added to the soil. The plants were grown during a typical tropical dry season. In one area the soil was covered with stones in order to hinder soil splash, and this area was separated from the others by plastic walls (ca. 60 cm in height). In the other areas normal conditions were used (Amaral *et al.*, 1992, 1994).

c) Chicken experiments: Different experiments were performed with varying contamination and decontamination periods at places where the soil was contaminated or uncontaminated with ^{137}Cs. The experiment was started with a breed of chicken that at the time of the accident were being kept at a small residential garden used later for this experiment. The Isa Brown and Leghorn breed of hens were also used in the experiment. All animals were fed with uncontaminated fodder. Meat and eggs were analysed for ^{137}Cs determination. The meat was separate from organs and bones, dried at increasing temperatures up to 90^{0}C and ashed at 40^{0}C. Eggs were weighed and cooked for sample preparation. After, the shell was removed and the albumen separated from yolk; all were weighed separated (Amaral *et al.*, 1992, 1994a).

All ^{137}Cs measurements were performed by gamma spectrometry using germanium detectors from ORTEC, with resolution from 1.7 and 2.0 keV and relative efficiencies from 11.6 to 33 %. Different counting geometric were used depending on the type and size of the samples to be analysed. Energies and efficiencies were calibrated with standard solutions. The counting time was 1000 min or until the statistical counting error was less than 10%.

3. RESULTS AND DISCUSSION

Figure 3 shows the air activity concentration in air as a function of the period of the experiment and of the precipitation data for the 3 location sampling (front yard, back yard and back yard at roof height). It can be observed the very slow long term decrease with time and a strong seasonally effect, with the higher values obtained during the dry season and the lower during the wet season. The fact that the soil has became less erodible could explain the slow long term decrease with time, since the activity concentration of surface soil did not decrease during the experiment period (Table I).

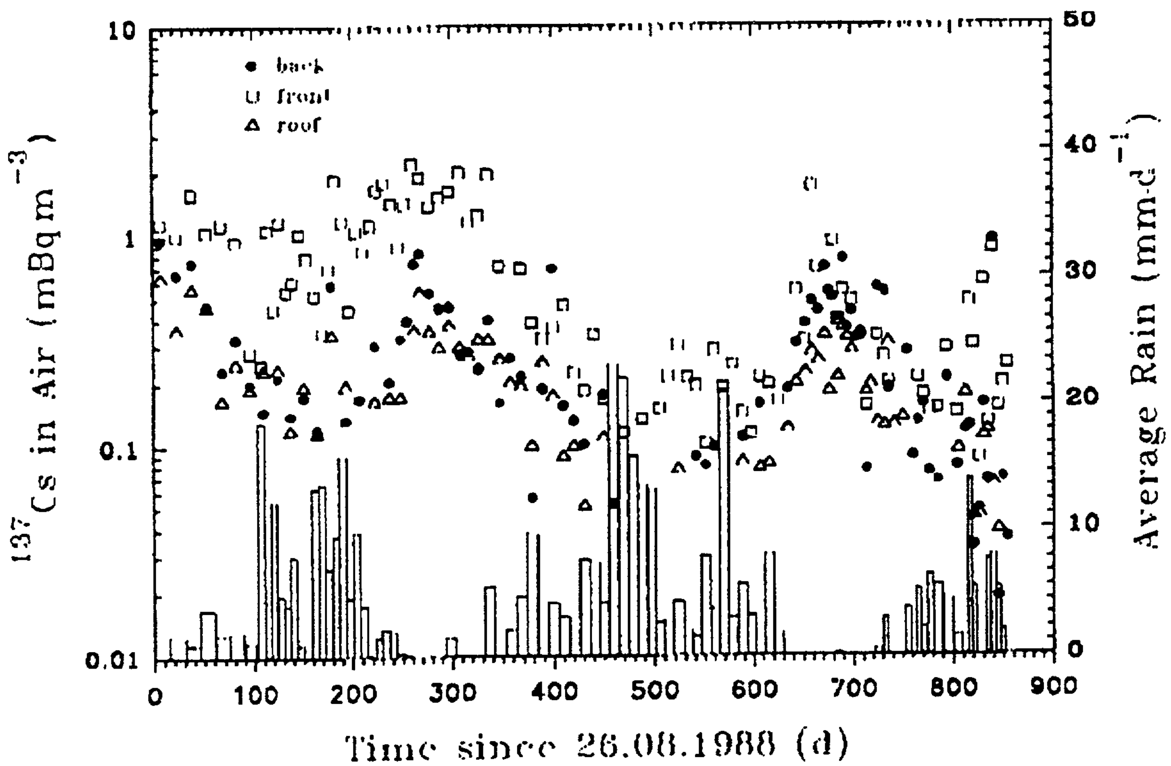


FIG. 3. Air activity concentration as a function of time and precipitation data for the 3 sampling locations.

TABLE I. ^{137}CS ACTIVITY CONCENTRATION IN SURFACE SOIL OF THE FRONT AND BACKYARD OF THE EXPERIMENTAL HOUSE DURING THE PERIOD OF THE EXPERIMENT.

Sampling Period	Sampling Location	Activity Concentration (Bq kg^{-1})			
		Average	SD	number of samples	Minimum-Maximum
May 89	Frontyard Backyard	11791 3544	4791 922	10 8	6112-20457 1808-5006
Out 89	Frontyard Backyard	14730 2954	5751 1009	10 10	6734-21950 1636-4582
Mar 90	Frontyard Backyard	14650 4882	3230 1732	10 8	8148-18460 1313-7115
Jul 90	Frontyard Backyard	13110 2656	2576 1256	10 9	9986-17410 1319-4620
Jan 91	Frontyard Backyard	7345 2393	3001 923	10 8	3452-14077 1443-4415

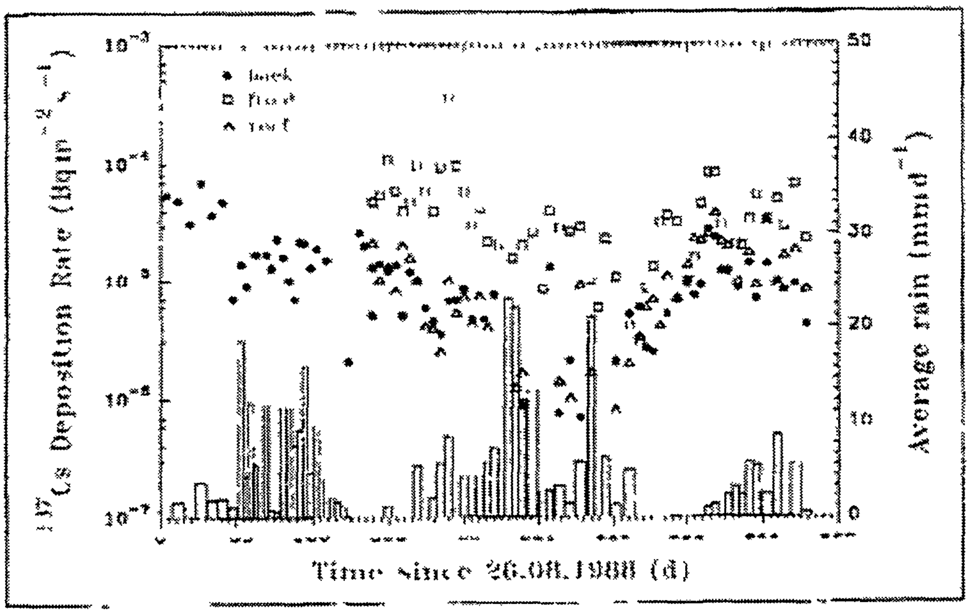


FIG 4 Total deposition rate as a function of time and precipitation data for the 3 sampling locations

The same can be observed for the deposition rate measurements. Figure 4 shows the total deposition rate as a function of the period of the experiment and of the precipitation data for the 3 location sampling. Again, the higher values were obtained during the dry season and the lower during the wet season.

From these results, very high values for the rate of deposition were derived suggesting that much of the ^{137}Cs activity in air must be attached to aerosols too large to be detected by the EPA air sampler used. This fact could be confirmed with cascade impactor measurements that were compared with those obtained with the EPA air sampler. Table II shows the deposited material measured in the tubs and those predicted based on four stages cascade impactor measurements and using size dependent deposition velocities from the literature. As one can see, 30 to 70% of mass in air was invisible to the EPA air sampler in both sampling location. Because of the low air activities we could not measure the ^{137}Cs activity on the impactor stages.

TABLE II. MEASURED AND PREDICTED DEPOSITION RATE AND MASS OF AIR INVISIBLE TO THE EPA AIR SAMPLER.

Location	Mass deposition rate ($\mu g\ m^{-2}\ s^{-1}$)		"Invisible" mass in air ($\mu g\ m^{-3}$)
	Observed	Predicted	EPA-type
Backyard	5.35	2.15	79 (49%)
	5.30	2.36	92 (51%)
	7.67	0.7	90 (60%)
	4.55	2.05	97 (59%)
Frontyard	10.7	2.45	115 (50%)
	11.6	3.12	170 (63%)
	7.34	1.84	117 (66%)
	7.33	3.10	79 (36%)

Figure 5 shows the ^{137}Cs activity concentration in street dust as a function of the distance from 57th street in sampling performed in July 1991. The highest values of the ^{137}Cs activity were restricted to the area of primary contamination. This could be explained by the fact that most activity is probably attached to large particles of soil that cannot travel long distances and are deposited locally and also due to the complex pattern of urban structures. Because of that, we do not expect, also for the future, a significant spreading of ^{137}Cs in the city.

Table III shows the estimate of the contribution of direct deposition, root uptake and soil splash to the ^{137}Cs uptake by lettuce and green cole. As one can see, for those vegetables which grow near the ground (that is up to 30 cm height) the contribution of the soil splash was up to 80%.

TABLE III. CONTRIBUTION OF DIRECT DEPOSITION, ROOT UPTAKE AND SOIL SPLASH TO THE ^{137}CS UPTAKE BY LETTUCE AND GREEN COLE

Cultivation area	Lettuce (Bq kg^{-1}_{dry})			Green Cole (Bq kg^{-1}_{dry})		
	Deposition	Root	Splash	Deposition	Root	Splash
with stones	17 (23%)	55 (77%)	-	125 (61%)	81(39%)	-
near wall	17 (7%)	56 (22%)	183 (71%)	125 (25%)	83 (17%)	284 (58%)
inner border	17 (3%)	59 (10%)	500 (87%)	125 (28%)	86 (20%)	231 (52%)

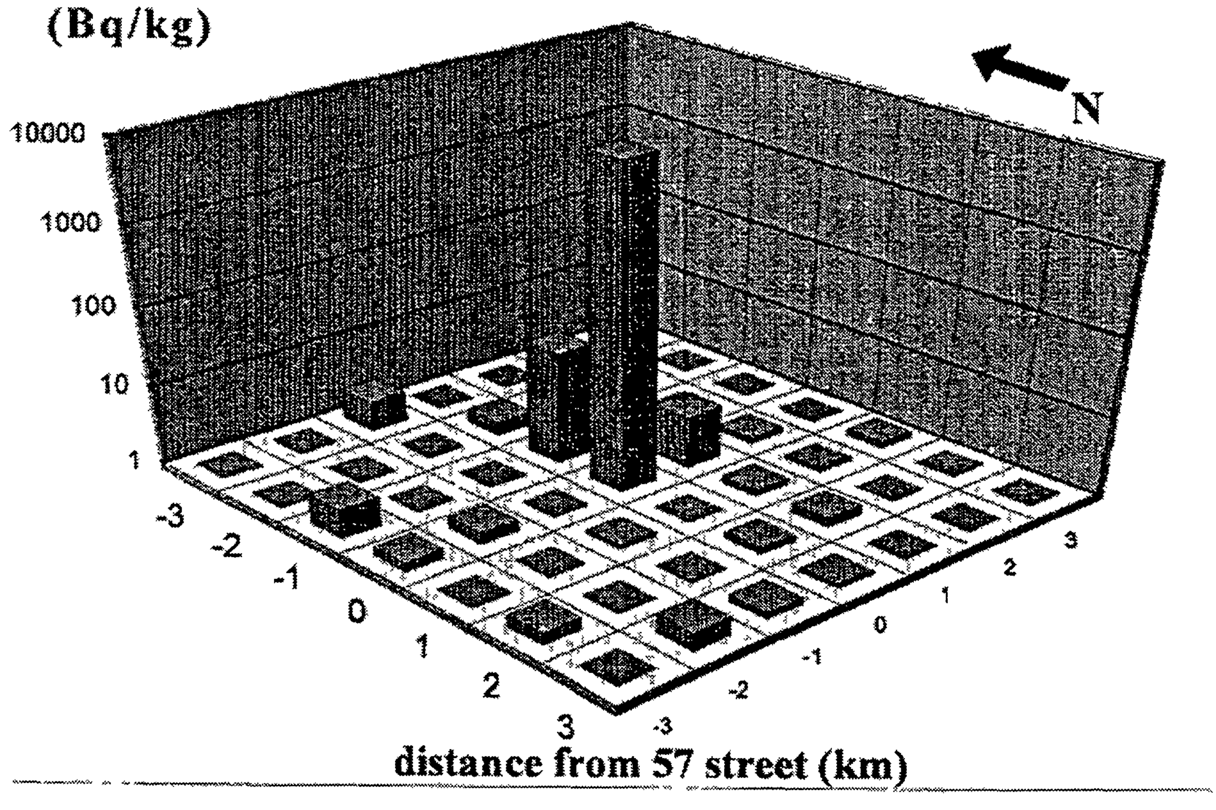


FIG 5. ^{137}Cs activity concentration in dust samples as a function of the distance from 57th street Sampling performed in July 1991

Regarding the chicken experiment, the distribution and biological half-lives of ^{137}Cs in poultry after prolonged ingestion of contaminated soil were studied. The number of chickens available for the measurements was not large enough to be able to obtain statistically significant conclusions concerning the chicken meat. Tables IV and V show the results for ratio respectively egg constituent and meat to soil activity for the three different types of chicken studied.

TABLE IV. CONCENTRATION RATIOS FOR ^{137}CS UPTAKE INTO CHICKEN EGGS BY SOIL INGESTION.

Experiment/Species	Egg Constituent	Concentration Ratio ($kg_{soil}\,kg^{-1}_{egg}$)	Concentration Ratio (kg_{soil}/egg)
Black India	albumen yolk edible part	7.5×10^{-3} 1.6×10^{-3} 9.1×10^{-3}	4.7×10^{-3} 9.7×10^{-3} 5.7×10^{-3}
Leghorn	albumen yolk edible part	6.9×10^{-3} 1.5×10^{-3} 8.3×10^{-3}	3.9×10^{-4} 8.2×10^{-5} 4.7×10^{-4}
Isa Brown	albumen yolk edible part	1.3×10^{-2} 2.7×10^{-3} 1.6×10^{-2}	7.8×10^{-4} 1.6×10^{-4} 9.4×10^{-4}

TABLE V. CONCENTRATION RATIOS FOR THE ^{137}CS UPTAKE BY MEAT DUE TO SOIL INGESTION.

Experiment/Species	Concentration Ratio ($kg_{soil}\,kg^{-1}_{meat}$)
Black India	$8.2\ 10^{-2}$
Leghorn	$5.2\ 10^{-2}$
Isa Brown	$3.1\ 10^{-2}$

4. CONCLUSIONS

The strongly heterogeneous, locally restricted contamination in Goiânia and a virtual lack of any previous contamination from atmospheric atomic bomb test and from Chernobyl accident permit ideal studies of the fate of ^{137}Cs in the urban environment.

The air concentration and deposition rates of resuspended ^{137}Cs in Goiânia 5 years after the primary contamination show a very slow long term decrease with time but a significant seasonally effect.

The spreading of ^{137}Cs in this city is slow. After 5 years most of the activity is still confined to less than 200 m of its initial deposition.

Resuspension does not contribute much in Goiânia to the total radiation exposure, but can lead to significant local contamination of agricultural products, equipment, structures, etc.

REFERENCES

[1] AMARAL, E.C.S., PARETZKE, H.G., PIRES DO RIO, M.A., CAMPOS, M.J., Radiological measurements after the Goiânia accident, Proceedings of the 9th International Congress on Radiation Research, Toronto, 7–12 July 1992 460–465.

[2] AMARAL, E.C.S., PARETZKE, H.G., CAMPOS, M.J., PIRES DO RIO, M.A., FRANKLIN, M., The contribution of soil adhesion to radiocaesium uptake by leafy vegetables, Radiat Environ Biophys **32** (1994).

[3] AMARAL, E.C.S., PARETZKE, H.G., CAMPOS, M.J., PIRES DO RIO, M.A., FRANKLIN, M., Transfer of ^{137}Cs from soil to chicken meat and eggs, (submitted for publication) (1994a).

[4] HEALTH PHYSICS, The Goiânia Radiation Accident, New York: Pergamon Press, Vol. 60, No. 1, Special Issue (1991).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, The Radiological accident in Goiânia, ISBN 92–0–129088–8, Vienna (1988).

[6] PIRES DO RIO, M.A., Ressuspensão e disseminação de ^{137}Cs em áreas urbanas: a experiência de Goiânia. Master thesis, Federal University of Rio de Janeiro, (in Portuguese) (1993).

[7] PIRES DO RIO, M.A., AMARAL, E.C.S., PARETZKE, H.G., The resuspension and redeposition of ^{137}Cs in an urban area: the experience after the Goiânia accident, *J. Aerosol Sci.* **25** (1994) 821–831.

THE BEHAVIOUR OF ^{137}CS IN THE AQUATIC ENVIRONMENT

M.E. DE LUCCA
Instituto de Biofísica,
Universidade Federal do Rio de Janeiro,
Cidade Universitário,

J.M. GODOY
Instituto de Radioproteção e Dosimetria,
Comissão Nacional de Energia Nuclear,

Rio de Janeiro, Brazil

Abstract

THE BEHAVIOUR OF ^{137}CS IN THE AQUATIC ENVIRONMENT.

Through ^{137}Cs concentration profiles in sediments from Rochedo Reservoir, it was possible to estimate the amount of this radionuclide (94 TBq) which has reached the Meia Ponte River system, as a consequence of the Goiânia Radiological accident in 1987. Based on in-situ measurements as well as on laboratory studies, the influence of NH_4+ concentration on the K_d value was also investigated. The results have shown that for high NH_4d+ concentrations there is a clear correlation between both parameters. It was also observed the influence on the ageing effect on the ^{137}Cs release from the sediment, as well as of the illite content on it.

1. INTRODUCTION

During the Goiânia accident it was possible to prove that ^{137}Cs reached the Meia-Ponte River through the rain water and the sewage system [1,2] (Fig.1). The first dam after the Goiânia City is the Rochedo Dam, and is, of course, where the contaminated sediments should accumulate.

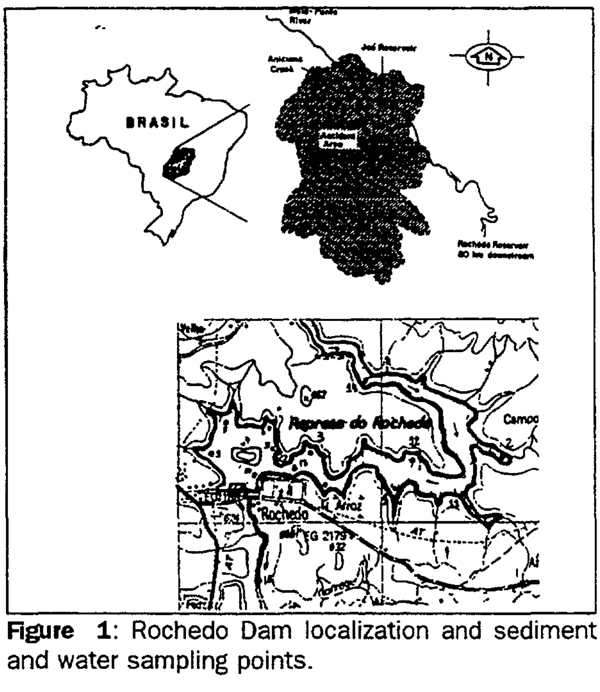


Figure 1: Rochedo Dam localization and sediment and water sampling points.

The Rochedo Reservoir has an area of 7.6 km^2, and is surrounded by cattle farms and is used for recreation and sport fishing all year (Fig.2). Fifteen stations were established for sediment and water sampling, thirteen inside the dam, one upstream and another downstream.

The first sampling campaign at Rochedo Dam was performed during August/88, and covered not only sediments but also biological samples (Table I)[2].

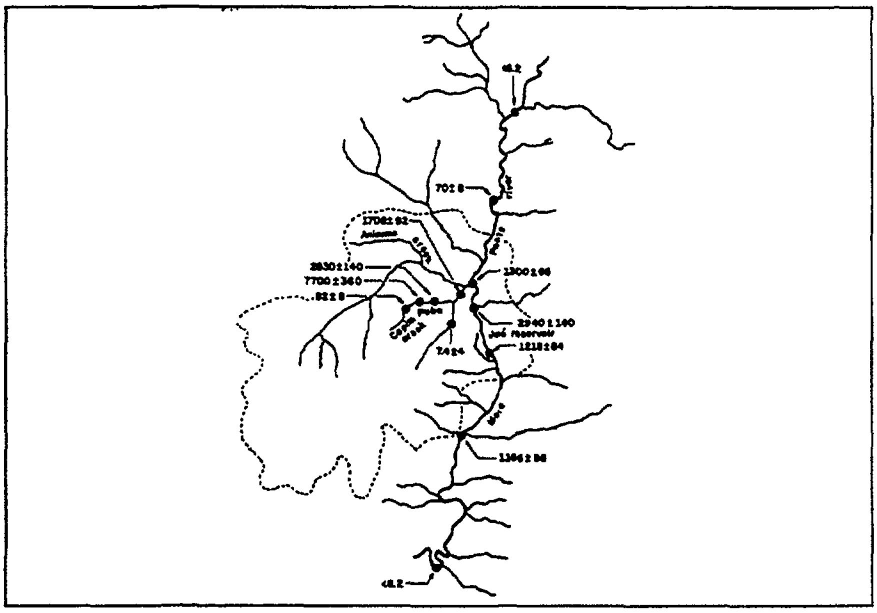


Figure 2: Contamination survey of the Meia-Ponte system. results obtained on 06/10/87 and given in Bq/kg_{dry}.

Table 1: ^{137}Cs in selected elements of the Rochedo Reservoir biota. Survey performed in August/88.

Organism	**^{137}Cs concentration (Bq/kg fresh)**
Benthic fish (*Goslinia* sp.)	8.0 ± 0.4
Piranha (*Serrasalmus* sp.)	9.5 ± 0.6
Pike (*Hoplias* sp.)	13.9 ± 0.7
Algal mats (*Spirogyra* sp.)	<3.2
Water hiacynth (*Eichornia* sp.) young, whole	0.33 ± 0.09
Water hiacynth (*Eichornia* sp.) mature, leaves	<0.25
Water hiacynth (*Eichornia* sp.) mature, roots	0.41 ± 0.07
Floating grass mats[a] (above water parts)	0.9 ± 0.2
Floating grass mats[a] (rhizome)	1.0 ± 0.1

a Not identified

Based on ^{137}Cs profile in sediments, the ^{137}Cs inventory in Rochedo Dam was estimated in 94 GBq. In-situ distribution coefficients (K_d) for ^{137}Cs were calculated based on the caesium content in the solid and in the pore water phases. The obtained values ranged between 10^2-10^3 L/kg.

It was previously observed by other authors, see e.g. Evans[3] or Pardue et al[4], a relationship between ammonia in porewater and K_d. Due to the low ammonia concentrations found on the Rochedo Dam sediments porewater, the same correlation was observed only when the ammonia concentration was higher than 20:M (Fig.3).

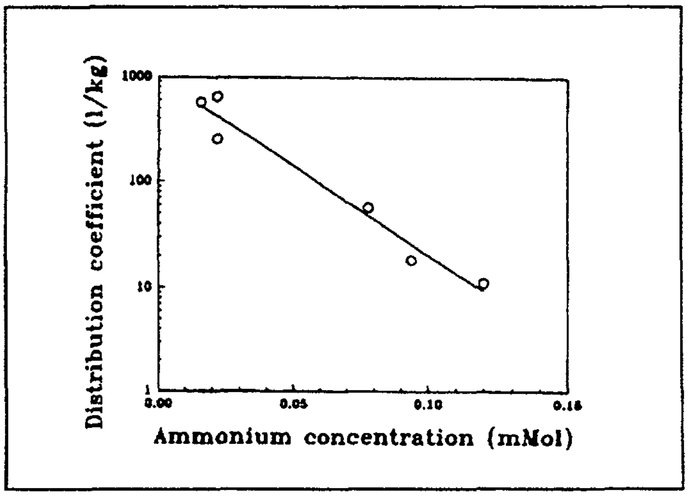


Figure 3: Correlation between in-situ K_d and ammonium in sediments from Rochedo Dam

Based on batch experiments, it was possible to show (Fig.4) that:

- There is an effect of the contamination age on the caesium desorption from sediments,
- Sediments with a higher illite content have a higher K_d and a lower reversibility of the caesium adsorption on the sediment.

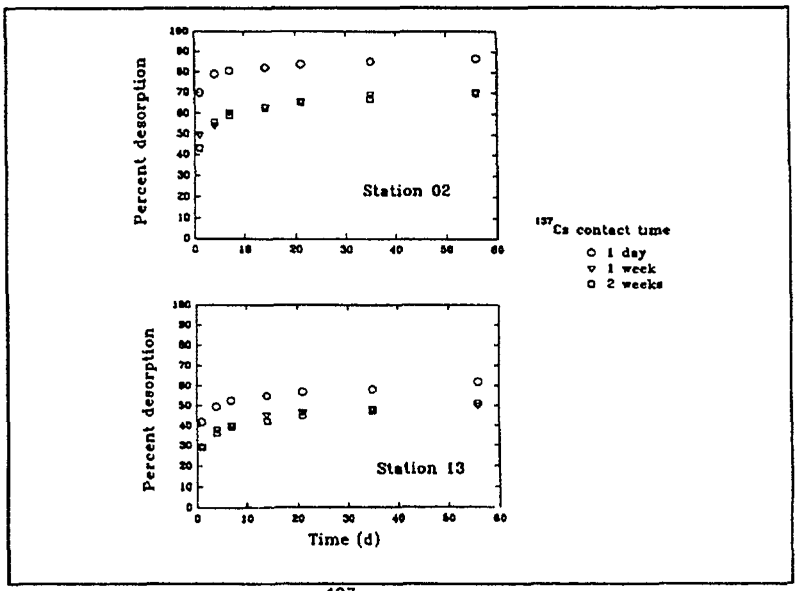


Figure 4: Kinectics of ^{137}Cs desorption from sediments from Rochedo Dam for different contact times. (Illite contet of sediments from station 13 > station 2).

2. CONCLUSION

- The ^{137}Cs amount which reaches the Meia Ponte River system after the Goiânia Accident can be estimated in 94 GBq
- The K_d values for the Rochedo Dam sediments are between 10^2 and 10^3 L/kg
- When the ammonia concentration in porewater is higher than 20:M, there is a negative correlation between ammonia and K_d
- There is an ageing effect on the reversibility of the caesium desorption from sediments
- The illite content has an influence both on the K_d value as well as on the contamination reversibility

ACKNOWLEDGEMENTS

The authors want to thank Dr. Rob Comans, ECN, The Netherlands, for the helpful and fruitful co-operation and the International Atomic Energy Agency for the financial support.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, The Goiânia Radiological Accident, IAEA, Vienna (1988).

[2] GODOY, J.M., GUIMARÃES, J.R.D., PEREIRA, J.C.A., PIRES DO RIO, M.A., Health Physics **60** (1991) 99–103.

[3] EVANS, D.W., ALBERTS, J.J., CLARKE, R.A. III, Geochim. Cosmochim. Acta 47 (1983) 1041–1049.

[4] PARDUE, J.H., DELANUE, R.D., PATRICK, W.H. Jr., WHITCOMB, J.H., Health Phys. **57** (1989) 781–789.

XA0054912

SCIENTIFIC BASES FOR DECISION MAKING AFTER A RADIOACTIVE CONTAMINATION OF AN URBAN ENVIRONMENT: THE DESIGN OF THE REPOSITORY

A. TRANJAN FILHO
Comissão Nacional de Energia Nuclear,
Rio de Janeiro, Brazil

Abstract

SCIENTIFIC BASES FOR DECISION MAKING AFTER A RADIOACTIVE CONTAMINATION OF AN URBAN ENVIRONMENT: THE DESIGN OF THE REPOSITORY.

The paper to be presented will discuss, specifically, technical aspects of the Repository design in case of urban contamination. It will be emphasise what to decide, how to decide and what are the difficulties to decide. The case of Goiânia it will be used as demonstration, in some cases, as a practical example.

1. INTRODUCTION

This paper will discuss specifically the basis for decision making and the technical aspects related to the design of a provisional repository in case of an urban environment contamination.

The following points are considered basic for our discussion:

- every accident is unique
- in emergency situation the solution has to consider the local supplying capacity
- the decontamination methods will define the design parameters of the repository
- the volume and type of waste and packages are the basis for physical and structural design of the repository.

All the above items could be detailed and many sub-items specified but, at once, it becomes clear that a provisional repository designed during an emergency is completely different from those designed in a normal situation where it is established, from the beginning, package dimensions, maximum dose rates, the final product quality, and so on.

2. ACCIDENT EVALUATION (EVERY ACCIDENT IS UNIQUE)

It is clear that the same scenario, occurring in different laces will have different solutions. Let us suppose a hypothetical case:

During the transport of a radioactive liquid source through a city, an accident happens. Not only experts but the layman can understand that if the accident occurs in a big city, in a very important street, it would have distinct repercussion than if it occurred in a small town. Certainly the decontamination ways, type of equipment and recipients to be used would be totally, or partially different, in each case.

This is a very simplistic example but sufficiently good to show that the same event, happening in different places will have distinct solutions and confirm the thesis that "every accident is unique".

Based on the above, we conclude that the appraisers (the group responsible for evaluating the available parameters and, based on them, propose the most efficient and safe solution) have to be as experienced as possible because all the actions will depend on their evaluation and this will determine the repository design and construction basis.

In the most urgent cases, the appraisers have to decide in a short time, based on a few data, about a lot of design parameters. This shows the difficulties and the necessity to work with experienced people. They have to be sensible and dominate a great number of disciplines.

As an example some questions are presented below that have to be answered by the appraisers during the evaluating process:

- the volume of generated waste; (What will be the volume?)
- quality of the encapsulated product; (What will be the quality of the encapsulated product? This characteristic is directly related to final volume, type of recipient, decontamination time, occupational doses, etc.)
- types of recipients; (What recipients have to be used? On this choice will depend the final volume, the quality of the product, the handling conditions, the transport and the final deposition)
- admitted exposure rate; (What exposure rate will be admitted on the recipients surface? On this decision will depend the final volume, occupational doses, decontamination time, transport conditions, etc.)
- maximum distance from contaminated places to the repository; (What is the maximum acceptable distance from the contamination focus to repository? This decision reflects the risk of transport, final decontamination costs, eventual delays, etc.)
- waste transport; (What type of vehicle will be used to transport the waste? This is a very important question, considering that it can influence the recipient dimensions (in order to have a best transport arrangement), in the access ways up to the repository (because depending on the final vehicle weight and dimensions it could be impossible to pass through bridges or execute radical maneuvers, etc.)
- site characteristics; (What are the site characteristics? From those are dependent the equipment to handle the recipients, type of recipients, occupational doses, storage risks, etc. and mainly, the repository concept. It is relevant to observe that the decision about the local will be based on a very small quantity of information on geology, pedology, hyrology, hydrogeology, access roads, etc.)
- personnel; (How about the profile and number of persons involved in decontamination services? It is highly important the number and professional profile of the people involved. This will influence the service continuity, in case of group substitutions, the occupational doses, the decontamination schedule, etc. The discipline of the groups is an objective to be reached. Highly qualified groups, not disciplined are a good way to the failure.)
- structure, (medical support, engineering, technicians, geology, equipment, vehicle, etc.). (What is the best structure considering every area? The decontamination success, the schedule, etc., depend on the mounted structure. The above mentioned areas are only examples. There are many others so important or more than those above. Warehouse, commercial area, etc. Depending on the gravity, urgency and dimension of the accident the structure can reach considerable size, demanding all order of resources.)

As we can see there are a lot of variables influencing the decision process. Once more, it becomes clear that it is absolutely necessary a group of well trained appraisers in order to have in a short time the most efficient and safe solution.

3. SOLUTION IN EMERGENCY SITUATION (HAS TO BE CONSIDERED THE LOCAL SUPPLYING CAPACITY)

- Availability of the local suppliers; (What are the local suppliers availability? Probably this is one of the most important evaluations because, based on that, sometimes, it can be given a quick, safe and efficient solution. The supplying capacity is related directly or indirectly to every decisions of the appraisers.

Let us suppose that the accident happens in a small city with no industrial resources, generating a large volume of waste. This scenario will put the appraisers in a very delicate situation because if there are no industrial resources, it will be impossible to manufacture proper recipients for the situation. Let us consider that the manufacturing of the recipients in other places is expensive and would introduce unacceptable delays. Let us still suppose that the city has reasonable conditions to produce a specified type of concrete. In this case, the final repository could be immediately constructed, instead of a provisional solution, or concrete containers to be transported in the future.

However, a provisionary solution has to be always tried, which permits any future intervention. The construction of the final repository would oppose every requirement of previous studies of environment impact and rare would be the cases where it could be justified.

Based on the above, it becomes clear that it is absolutely necessary to know the local suppliers availability because this will influence every decision of the appraisers.

4. PROCESS AND DECONTAMINATION WAYS

- Decontamination methods; (On this decision will depend the final waste volume, type of recipients, equipments, decontamination schedule, number and profile of workers, occupational doses, transport vehicles, etc.)

The process and decontamination ways have to be always the simplest. This is an important condition to be assumed in case of medium or big radiological urban accidents. The urgency is returning the city to normal condition. Sometimes, this will suggest unorthodox decontamination methods, but it is very important that this condition do not inhibit the appraiser. The appraiser has to have in mind that the process and decontamination ways are not absolute or independent questions. In other words, the process and decontamination ways are directly related to waste volume, which is related to the type of recipients, which is related to the transport and safety storage conditions and all of them are related to the repository. It is this interrelationship, here simplified, that renders the decisions' difficulty, because all of them have to be taken into account, in block, as a whole, considering simultaneously, every variable. This situation amplifies drastically the perspective of error.

Let us suppose a case where the transport is the most delicate point, in other words, the transport has to be minimized. In this case, if possible, the volume of waste has to be reduced, and so, the process and decontamination ways become crucial for the decisions.

Let us suppose a case where the number of workers have to be the minimum. This situation determines very low occupational doses, and, once more, the process and decontamination ways will be decisive.

5. VOLUME, TYPE OF WASTE AND RECIPIENTS

Practically thesej items define the basis of physical and structural design of the repository, so they must have special attention from the appraisers.

Once more, we call your attention to the fact that the complication factors are the interrelationship among the variables and the few quantity of information present in the evaluation. As cited before, other factors as important as those mentioned above are the number and profile of the appraisers. Big teams normally delay the decisions and small teams increase the chance of errors.

6. REPOSITORY OF GOIÂNIA

In this chapter we will talk about the repository of Goiânia, constructed during the radiological accident with ^{137}Cs, occurred in September 1987.

Here we will show some practical examples of the decision process and how were defined some of the design parameters to construct the repository of Goiânia.

6.1. Goiânia — Evaluations

6.1.1. The Accident

A complete (possible) radiometric map of the accident was made in order to determine the following parameters:

- number of contaminated areas; (Seven big areas were found and several ones dispersed in the city)
- total volume of waste (without treatment); (Probably 3500m^3 in the big areas and 1500 m^3 in the others)
- types of waste; (More than 90% inorganic, basically soil and debris, and 10% organic)
- exposure rates; (Up to 100 R/h in the big areas and below 200 mR/h in the others)
- access condition to the areas; (Easy for workers and equipments)
- decontamination urgency; (Any delay could mean contamination possibility of other areas).

6.1.1.1. Indicators

The above data did permit to do a first evaluation with the following indicators:

- it would be important to work simultaneously in several areas, therefore, a big and organized infrastructure and a considerable quantity of workers, equipments and expensable items would be necessary;
- the volume of waste did require special recipients, in order to permit working with big equipments;
- considering the schedule, all of the waste, except the organics one, would be encapsulated without treatment. However, this had to be done considering the possibility of future interventions. Practical methods for organic waste encapsulation were established;
- in order to facilitate the handling, transort, decontamination, etc., big exposure rates on the surface of the recipients had to be avoided;

- heavy equipments could be used in every areas;
- it was necessary to establish a quick and organized decontamination considering the urgency.

6.1.2. Local Resources (Local Supply Capacity)

The evaluation of the local resources did present the following results:

	very good	good	regular	bad	null
earth moving	x	—	—	—	—
concrete construction	x	—	—	—	—
metallurgy	—	x	—	—	—
equipments	—	—	—	x	—
vehicles	—	—	x	—	—
expendable items	—	—	x	—	—
workers	—	—	x	—	—
radioprotection	—	—	—	—	x

6.1.2.1. Indicators

The above data did permit to do a second evaluation with the following indicators:

- earth moving could be performed immediately;
- concrete construction could be ordered immediately;
- it was possible the manufacturing of metallic recipients, within a reasonable time of delivery (it was discarded the manufacturing of concrete containers considering their final weight, time of construction, handling problems, transporting difficulties and the possibility of future interventions);
- every operation with light equipment had to be as simplified as possible (to avoid increasing the occupational doses);
- considering the existing vehicles, the repository had to be constructed as near as possible to the contaminated areas;
- small quantities of common materials, in small quantities, could be acquired locally;
- Goiânia had skilled workers, but one could not count on them due to generalized fear;
- everything related to radioprotection (people, expendable items, equiment, etc.) had to come from another part of the country (this was decisive in the dimensikoning of the teams).

6.1.3. First Conclusions

The waste quantity and the decontamination urgency, showed, from the beginning, that the repository had to be unsophisticated.

The repository site had to satisfy minimum conditions, the storage would be done in open sky, avoiding elaborated constructions but considering the mechanisms to avoid any contamination of the area.

6.1.3.1. Minimum Local Characteristics

Based on the available data it was requested to local authorities an area with the following minimum characteristics:

- if possible, in a public area; (To avoid social problems. Basic requirement for local selection process.)
- if not public not productive; (To avoid social and environmental problems. Basic requirement for the local selection process.)
- with approximately 400 m width and 400 m length; (To facilitate the design related to radioprotection. Specific requirement for Goiânia.)
- as plane as possible; (To reduce earth moving and to facilitate constructions. Specific requirement for Goiânia.)
- high, compared to surrounding; (To avoid flooding problems. Basic requirement for local selection process.)
- with electric power; (To facilitate construction and avoid delays. Specific for Goiânia.)
- near Goiânia city; (To reduce the time and risks of transport. Specific for Goiânia.)
- distant from parks, natural and indigenous reserves, scale production zones and with low demographic density; (Basic requirement for local selection process.)

OBS: Based on these requirements it was selected an area distant 23 km from the center of Goiânia (main contaminated areas) and 1,5 km from Abadia de Goi<s, small city with a very low number of inhabitants at that time.

6.1.3.2. Design Concept of the Goiânia Repository

The Goiânia repository concept was based on the above indicators and satisfying the following questions:

- what repository could be constructed in open sky with low possibility of environment contamination? (Independently of the recipient types, they have to be covered. It was adopted "lonilvinil" (commercial Brazilian name), the same material used to cover products during road transportation. This is a very resistent material and easy to be bought in Goiânia.)
- how to avoid the remotion of the "lonilvinil" by winds or other mechanisms? (It was adopted to use "fitin" (commercial Brazilian name), type of tape, very resistent, easy to apply and locally available.)
- how to avoid soil contamination in case of eventual covered recipient leakage? (It would be constructed a concrete basis proper to absorb and retain any contamination.)
- how to guarantee, in spite of the concrete basis, any soil contamination? (The concrete basis would be put over a concrete platform with a sampling system.)
- what to do in case of contamination detection by the sampling system? (It would be necessary to localize and correct the failure, to decontaminate and encapsulate the waste. Therefore, sampling and decontamination procedures were developed.)
- how to avoid ground water contamination? (Various measures were taken to avoid ground water contamination:

* the soil under the platforms and up to 10 m of their contour were waterproofed by the same method used in road constructions. In this way the dilution factor would become higher and the contamination would be maintained on the surface or near it protecting the ground water;
* the repository area would be prepared in such a way to direct all the rain water to the same point. It would be constructed a barrier, maintaining the water inside the repository area, diluting any contamination and sparing the ground water).

OBS: The possibility of the repository contamination was remote since the recipients were new and would be covered. However, during the filling process, the recipients could become externally contaminated. Taking that in account, three procedures were established:

- every recipient would come into the contaminated areas externally protected by a plastic bag;
- every recipient would be tested, confirming no contamination, before its transference to the transport truck;
- every recipient would receive, before its entrance into the contaminated area a layer of dry cement in order to absorb any free liquid present in the waste. This would enlarge the recipient structural life.

These procedures did consider not only the immediate problems but others related to long term storage.

6.1.4. Recipients

It was fundamental to define the recipient type or types to be used. On this choice would depend the efficiency of the decontamination process:

- what types of recipients? (There was only one well known recipient available, in the country, in a great number (200 l drums). However, due to its characteristics their use would mean, delay in the schedule, because approximately 30.000 drums would be used and the decontamination would be done manually. Being so, it become clear that another type of recipient had to be manufactured, in order to permit the mechanical decontamination (drums were used while the other recipient was being manufactured));
- what dimensions should the recipient have? (These dimension had to be in accordance with the repository dimensions, in order to minimize the costs, construction time and to facilitate the recipient arrangement on the platforms and basis. These dimensions had to be in accordance with transport possibilities, occupational dose conditions, etc. Therefore, the new recipient dimensions had to be multiples (for great capacity) of the drum dimensions (diameter 60 cm/height 90 cm)).

Note: Steel plates with the required specification and various widths (from 0.90 m up to 1.60 m) were locally available. The plate with 1.20 m was elected, because 1.20 m is a multiple of 0.60 m (drum diameter). This dimension had a lot of manufacturing advantages, reducing welding length, construction time, recipient failure possibility, etc.

A cube with an edge of 1.20 m would be constructed. These dimensions were easy to handle, empty of full. The final weight of the metallic box, with the most dense material would be compatible with the capacity of the existing vehicles. The cubic shape gave an optimum volume, near to nine times the drum capacity.

7. DISCUSSION

Let us do a brief analysis of the design development:

- local suppliers — 1.20 m plates;
- 1.20 m plates did permit the manufacturing of recipients, easy to handle, to transport, and compatible with the drums arrangement, that is, four metallic boxes, made of 1.20 m plates, put one beside another are equivalent to four pallets with four drums each, one beside another;
- boxes and pallet dimensions did determine the dimension of the concrete basis;
- basis dimensions, the necessity of equipment movements and exposure rates did define the number and the dimensions of the concrete platform;
- the distance between platforms and between platforms and fences did determine the necessary area for the repository.

Therefore, as a simplification, it could be said that the dimensions of the existing plates, in Goiânia, did determine the repository design. It is clear this is not an absolute truth but, this fact made a big contribution.

There were a lot of other parameters influencing the decisions, for example:

- the transport capacity did determine;
  * the maximum recipient weight (important in the dimensions definition);
  * maximum admissible distance from the main focus up to the repository; the contamination levels and local conditions did determine:
  * the waste volume to be generated (this did influence the decision to construct specific recipients);
  * how many persons would be involved in the decontamination jobs and in the repository;
  * maximum admissible dose rates on the surface of the recipients;
  * the basis for design concerning radiological protection, etc.;
- the characteristics of the contaminated areas did determine:
  * process and decontamination ways;
  * types and equipment dimensions, etc.;
- the local supplying capacity did determine:
  * the dimension and profile of the workers;
  * the simplification of the repository design;
  * what should come from other suppliers outside Goiânia, etc.

As we can see, we could evaluate here each item, analysing their relationship, almost indefinitely. However, the most fundamental of the lessons learned in the Goiânia accident, concerning technical aspects, could be summarized as follows:

"Every accident is unique and will need specific solution. This will be as much better as better are the Appraisers."

SOCIAL AND ECONOMICAL ASPECTS IN THE SELECTION OF THE SITE FOR THE FINAL GOIÂNIA WASTE REPOSITORY

A.S. PASCHOA
Pontifíca Universidade Católica do Rio de Janeiro,
Departamento de Física,
Rio de Janeiro, Brazil

A. TRANJAN FILHO
Comissão Nacional de Energia Nuclear (CNEN) e
Furnas Centrais Elétricas,
Rio de Janeiro, Brazil

J.J. ROSENTHAL
Kibbutz/Gaash,
Israel

Abstract

SOCIAL AND ECONOMICAL ASPECTS IN THE SELECTION OF THE SITE FOR THE FINAL GOIÂNIA WASTE REPOSITORY.

Site selection criteria for low and intermediate level waste repositories are usually well established as far as the technological and scientific bases are concerned. However, social, cultural and economical aspects need to be examined on a case by case basis because there are many situations to be faced before succeeding to convince the public and authorities that a waste repository is to be built at any chosen site. In the specific case of Goiânia there is an ongoing process that started several years ago, to make the repository accepted by local, state and national authorities, and to answer legitimate questions raised by significant segments of the population. This paper will summarise those more relevant aspects concerning the site selection process for the Goiânia repository.

1. REMINISCENCES

I (ASP) would like to reminisce, as a starting point, how I became involved with the site selection for the final waste repository in Goiânia. Sometime in May 1990, I was surprised, as I was working in a laboratory at PUC–Rio, by an invitation to become one of the executive directors of CNEN. As a pre-condition to take the responsibility for the nuclear safety, radiation protection and safeguards at CNEN, I asked for an opportunity to visit the temporary waste repository in Abadia de Goiás, near Goiânia. I knew then that the management of such wastes would be quite an undertaking and could disturb other activities that I wanted to develop at CNEN, namely: emergency preparedness to respond to radiological emergencies and nuclear accidents (RENA); to implement and extend national safeguards to all nuclear facilities in Brazil; and, training personnel at several levels to carry through all the activities just mentioned. Pre-condition accepted, off I went incognito to Goiânia. However, upon my arrival at the Goiânia airport I was met not only by my colleagues, Drs. G. Laurer and C.A.N. Oliveira, who happened to be in Goiânia just by chance, but also, and not by chance, by press and television reporters. From that moment on I realised that whatever decision would be taken concerning the Goiânia wastes, it would have to have not only the agreement of federal, state and municipal governments, but also and mainly some kind of support of the local communities, and the local press and television.

Taking advantage of a pre-arranged International Atomic Energy Agency (IAEA) Waste Management Advisory and Program (WAMAP) mission to Brazil, I asked the members of the mission to draft clear cut recommendations concerning what to do with the wastes of the Goiânia accident, then in an open air interim storage site (ISS), as described earlier by one of the co-authors of this paper (ATF) (1). Much to my surprise the IAEA–WAMAP mission recommended only that the ISS should be covered, as soon as possible, to decrease the weathering based corrosion of the recipients. Immediately after the departure of the IAEA–WAMAP mission I called out a meeting with most of the people who had been involved, in one way or another, with the site selection and construction of the ISS. At the meeting there was general acceptance of the recommendations made by the IAEA–WAMAP mission, however, one of us (ATF) suggested that the time and money to be spent in covering the ISS could be better used to start building a final repository. I became instantly convinced by the arguments presented by ATF at an immediately subsequent private meeting and asked if he was willing to come to CNEN and work with me in the project.

The third author of this paper (JJR) had been involved in the management of the Goiânia accident from the time it was first communicated to CNEN and had built a favourable reputation with the local community, press and television. Details of the first decisions on remedial actions taken by CNEN after knowing about the accident can be found elsewhere (2). Taking into account his unique experience, JJR was asked to help make contacts with segments of the local community with the objective of gaining acceptance to the project of the final repository.

At this point the three of us were quite involved in debating a non-existent project of a final repository with anybody who wanted to debate; from elementary school teachers to university faculty, encompassing law organizations, Goiânia victims' associations, government officials and so on. Little by little a cloud of credibility started involving our honest answers, though we had almost nothing to present, as far as the actual project of the final repository was concerned, in addition to our good will to solve the problem created by the wastes left behind by the decontamination procedures that had ended four years earlier.

2. SITE SELECTION

Site selection criteria adopted by CNEN and accepted by all concerned encompasses the following (3):

- choice of a region of interest — which was the whole State of Goiás;
- identification of preliminary areas, based on factors such as demography, mineral zones, geographical contours, hydrological and hydrogeological conditions, ecosystems, seismicity, biological reserves, state parks, and Indian reservations — using those factors as excluding criteria, 189 preliminary areas were identified;
- selection of potential areas was based on the analyses of physiographic and geological aspects using more detailed maps to eliminate preliminary areas — 18 potential areas were then selected;
- "in loco" examination of potential areas to select candidate sites using a methodology that included aspects of geology, land and property use, aquifer depths, soil characteristics, and transportation requirements — three candidate sites were selected, being their distances from the ISS 100 km, 74 km, and 400 m, respectively.

All three candidate sites were presented by the Presidentj of CNEN to the Governor of the State of Goiás for a joint decision on site selection. Although the final decision on site selection had some untangible socio-political and economical components, there were also more tangible arguments in favour of the nearest site such as the following:

(i) it would minimise the risk of an accident during transportation;

(ii) the wastes could be treated and stabilized "in situ" before being transported to the nearby final repository because the increment in volume would not be a relevant factor in this case; and,

(iii) part of the land already belonged to the Government and the surrounding areas could be acquired.

3. A RADIOECOLOGICAL LABORATORY

Later, after the site selection had been concluded, it was possible to sell the idea to build a radioecological laboratory adjacent to the site and a public park surrounding it. Such initiatives helped to gain the acceptance of the lay and scientific communities concerned with the environmental impact of the repository.

One of the arguments often used in debates was that the worse environmental impact scenario would be not to build the repository before the corrosion reached a degree that radioactive material could leak. The project of the repository does not allow for any leaking. However, the only way to assure the public and scientists that there will be no leakage from the repository is to let them make the monitoring independently. One of the main objectives of the radioecological laboratory is to support independent research concerning the repository to be built.

Even before the radioecological laboratory will come into being there is at least one example of cooperation between university and government scientists, as far as data and information exchanges are concerned (4).

4. LIFETIME OF THE REPOSITORY

A question often raised in the debates was the one related to the lifetime of the repository. Such a question can be easily answered based on scientific, technological and regulatory arguments, but there is not one universally accepted answer when one enters the field of ethical dilemma concerning future generations. There is not any doubt that the individual risk associated with the repository is exceedingly small. However, even estimated risks between 10^{-8} and 10^{-12} that any one person will die prematurely from a radiation induced cancer pose an ethical dilemma (5).

In any case, an individual dose limitation equivalent to 0.3 mSv per year was adopted in Brazil taking into consideration criteria for radioactive waste disposal used in other countries (6). Such dose limit corresponds to a ^{137}Cs concentration of about 87 $Bq \bullet g^{-1}$ (4,6). A decay time of little less than 360 years would be required for all Goiânia radioactive waste to reach a concentration level below 87 $Bq \bullet g^{-1}$ and be technically considered exempt from regulatory control (6). Here it is worth mentioning that about 50% of the total waste volume is already under such a level and within 60 years approximately 80% of the waste will be below the exempt concentration level.

Thus, the repository needs to be built to last for at least 400 years. Such a length of time might appear to be trivial for most Europeans, however, one must bear in mind that there is not one standing structure in Brazil with such an age. This makes a lot of people uneasy about the repository. Only time and continuous monitoring will convince people that the final repository for the wastes of the Goiânia accident is safe.

5. CONCLUDING REMARKS

- The reminiscences regarding the decision making process to build the final repository for the Goiânia accident wastes seem to show that each accident is unique in its peculiarities.
- Local characteristics and local culture play important roles in decision making processes, not being clear whether experience gained in one accident can be promptly used elsewhere.
- The team of decision makers should be sure of themselves to the point that they are able to criticize each others positions before adopting a common defensible line in open debates with laymen and scientists.
- Independent monitoring survey, whenever possible, is desirable to assure critics that the statements made in debates will stand the proof of time.
- Ethical dilemma is by all means an unresolved question.

REFERENCES

[1] TRANJAN FILHO, A., Design of the repository, this Workshop.

[2] ROSENTHAL, J.J., ALMEIDA, C.E., MENDONÇA, A.H., The radiological accident in Goiânia: the initial remedial actions, Health Physics, **60** (1991) 7–15.

[3] PASCHOA, A.S., HEILBRON FILHO, P.F., MALAMUT, C., TRANJAN FILHO, A., Waste management in Brazil: basis to build the final repository for the radioactive waste from the Goiânia accident, Waste Management 93 (ROY, G., POST AND MORTON, WACKS, E., Eds.), Arizona Board of Regents, Vol. 1 (1992) 133–138.

[4] CAMPOS, T.M.P., VARGAS, E.A. Jr., VAZ, L.E., RIBEIRO, S.G.S., PASCHOA, A.S., TRANJAN FILHO, A., Geotechnical evaluation of the Goiânia ^{137}Cs accident, Proceedings of the Joint Canadian Society of Civil Engineering and American Society of Civil Engineering National Symposium, Toronto, Canada (1993).

[5] EISENBUD, M., PASCHOA, A.S., Environmental radioactivity, Nuclear Instruments and Methods for Physics Research **A 280** (1989) 470–482.

[6] PASCHOA, A.S., TRANJAN FILHO, A., ROSENTHAL, J.J., Revisiting Goiânia: toward a final repository for radioactive waste, IAEA Bulletin, **35** (1993) 28–31.

THE ROLE OF FUNLEIDE IN THE FOLLOW-UP OR ASSISTANCE TO THE VICTIMS OF THE GOIÂNIA ACCIDENT

XA0054914

Q.C.B. SANTOS
FUNLEIDE,
Goiânia, Brazil

Abstract

THE ROLE OF FUNLEIDE IN THE FOLLOW-UP OR ASSISTANCE TO THE VICTIMS OF THE GOIÂNIA ACCIDENT.

The FUNLEIDE (Fundação Leide Da Neves Ferreira) was created by the Government with the objectives of planning, organising, supervising and giving assistance to the persons involved in the radiation accident with ^{137}Cs in Goiânia.

The medical service of the FUNLEIDE is responsible for searching early signals for possible alterations caused by ionising radiation, such as cancer, cataract, genetic changes, etc., following a specific protocol for routine exams of the patients assigned Group I (with radiodermatitis and/or whole body dosimetry above or equal to 20 rads), Group II (no dermatitis, dosimetry below to 20 rads) and Group III (professionals who worked in the emergency phase of the accident as well as relatives and other persons who got in contact with patients from Group I and II).

The FUNLEIDE is formed by the following departments: Medical Department, Nursing Department, Laboratories, Department of Odonthology, Department of Psychology and Department of Social Service. Besides the routine exams, the Medical Department provides any kind of medical assistance for the population involved in the accident.

1. INTRODUCTION

When the most urgent problems after the Goiânia accident had been overcome and the most seriously affected patients had recovered from the acute radiation syndrome, radiodermatitis was under control and people were more calm from the psychological point of view, the Government from the State of Goiás created a public institution with the aim to continue the work carried out mainly by professionals from other states.

The Fundação Leide Das Neves Ferreira – FUNLEIDE was constituted by decreed number 2897 from February 11, 1988 with the objectives of planning, organising, supervising and giving assistance to the persons involved in the radiation accident with Cs-137 in Goiânia.

The implementation of research programs is also one of the aims of this institution, as well as the capacity and adequacy of its personal staff, co-ordination of co-operation with educational and research institutions, besides the promotion of courses, symposiums and studies.

Initially, the technical staff from FUNLEIDE was constituted by the majority of health professionals (doctors, nurses, psychologists and social assistants) who worked in the emergency phase of the accident, but later on odonthologist, biochemist and biomedical staff have been added to the group.

The body of clients from FUNLEIDE is constituted by people involved to any extent with the radiation accident in Goiânia, subdivided according to the level of commitment: Group I (55 patients), Group II (46 patients) and Group III (486 patients).

Specialised services from the institution are offered to patients by the departments which form FUNLEIDE. Work is carried out in an integrated manner by all departments, searching for comprehending solutions for the problems presented by the victims and their family nucleus.

2. MEDICAL DEPARTMENT

The medical service of the institution is responsible for searching early signals for possible alterations caused by exposure to ionising radiation, such as cancer, cataract, genetic changes, etc., following the protocol:

- Group I Patients (with radiodermatitis and/or whole body dosimetry equal or higher than 20 rads):
  I. every four months they are submitted to a clinical evaluation with routine exams such as complete hemogram, V.H.S., cholesterol, glycemia, uric acid, liver function test, urea and creatinine, among other exams;
  II. biannually they are submitted to hormonal dosage, onco-parasitic cytology (for women), routine for head and neck for patients with age above 40 years old;
  III. annual exams: sperm counting, breast ultrasonography and mammography (according to age), bone marrow biopsy and myelogram, immunological and ophthalmological profiles and digestive endoscopy.
- Group II Patients (no radiodermatitis, dosimetry lower than 20 rads):
  I. biannually they are submitted to clinical and routine laboratory exams (same as Group I every four months), routine for head and neck and onco-parasitic cytology;
  II. annual exams: breast ultrasonography and/or mammography plus hormonal dosage.
- Group III Patients (professionals who worked in the emergency phase of the accident as well as relatives and other persons who got in contact with patients from Group I and II:
  annually submitted to clinical and routine laboratory exams (same from Group I and II) and other exams according to medical criteria.

Besides the scheduled exams, the Medical Department gives support to any health alterations observed among those patients, not only related to radiation exposure but also offering different specialities on a daily basis such as medical clinics, paediatrics, oncology, gynaecology, cardiology and dermatology, also orienting people for specialists of other areas from the public and private systems.

3. NURSING DEPARTMENT

This Department offers ambulatory assistance giving aid to the Medical Department such as bandaging of wounds, backing exams (E.C.G.), preparation for other exams, administration of prescribed medicines, as well as orientation on basic notions of hygiene and health. It helps the doctors in clinical and surgical procedures of minor concern (debridement, biopsy). The medical schedule from Group I, II and III patients every 4, 6 or 12 months is also a competence of this department, obeying the periodicity for procedures in the department as well as the daily medical agenda.

4. LABORATORY

In the Laboratory, all the clinical analysis exams necessary for the follow-up of patients as well as the chromosome study to identify eventual cytogenetic alterations caused by radiation are carried out.

5. DEPARTMENT OF ODONTHOLOGY

This department is responsible for checking the oral health of patients regularly, preventing and making an early diagnosis of possible lesions. The patients are oriented on how to brush teeth correctly and rinse the mouth with fluorine. Regular treatment includes: prophylactics and tartar removal, restoring, surgery, odontopediatrics and fluorine application. The services which are not possible to be made at FUNLEIDE are sent to specialists. All the information taken along the years are carefully registered by means of studies and researches, many of which have already been published, with the aim to contribute to the history of radiation accidents.

6. DEPARTMENT OF PSYCHOLOGY

This department is responsible for:

- psychotherapeutic clinical work with children and adults which are available to do it;
- psychopedagogic follow- up of children with learning difficulties;
- intervention in crisis, focusing on the problem presented by the patient including psychological advising;
- psychological support during hospitalisation;
- use of psychological instruments such as anamnesis, tests, questionnaires and interviews for diagnosis and research purposes;
- study of cases in order to present to the different departments of the institution, suggestions on how to behave with patients.

7. DEPARTMENT OF SOCIAL SERVICE

The Social Service has among its tasks: to give explanations to the victims concerning social rights and means of obtaining them with the aim to facilitate access to benefits and services of the institution and out of it; to orient the patients on how to obtain social resources available in the community; to promote the capacity of patients for social contact and for solving their problems.

In the field of assistance, the Social Service is not providing direct concession of benefits (financial aid) at the moment but health follow up, by means of orientation, visits, etc.

In the field of education, it has been working on orienting and promoting speeches on hygiene, nutrition, and family budget, among others.

The Social Service also develops other activities among patients and their families such as: contact and orientation to the patient, triage, interviews, follow up, meetings, hospitalisation, exams, visits and obtention of jobs. Concerning the role of articulating and co-ordinating interchange with educational and research institutions, mainly in the State of Goiás, FUNLEIDE has been impaired by the difficulties that the scientific community imposes due to prejudice to the political character of the institution. Research institutions and universities have rejected co-operation with FUNLEIDE, and developed projects, researches about the radiation accident totally separated from the ones who have a greater number of data, knowledge and information on the subject. Worse than denying contribution to the development of Science is having a prejudicial attitude towards the elucidation of facts relative to the accident.

Among the grievous effects of this presumed anti-political attitude from scientists (mainly from the social area) with support from the media and population in general, there is the instigation to insecurity, fear, emotional instability and resentment from the victims towards FUNLEIDE, making it difficult for FUNLEIDE to play the most important role of the institution and suggesting a lack of competence of the only institution which is available, in a broad sense, to make the follow-up and assist this population affected by Caesium-137.

LIST OF PARTICIPANTS

Achar, M.E.	CNEN-Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Al-Arfaj, A.M.	Institute of Atomic Energy Research, King Abdulaziz City for Science and Technology, Kacst, P.O. Box 6086, Riyadh- 11442, Saudi Arabia
Alexakhin, R.	Institute of Agricultural Radiology, Kievsko Shosse, 249020 Obninsk, Kaluga Region, Russian Federation
Almeida, C.E.V.	Laboratório de Ciências Radiológicas, Universidade do Estado do Rio de Janeiro (UERJ), Rua São Francisco Xavier, 524, CEP 20550-013 Maracanã, Rio de Janeiro, Brazil
Alves, R.N.	Instituto Militar de Engenharia (IME), Rua General Tibúrcio, 80, CEP 22290–270 Praia Vermelha, Rio de Janeiro, Brazil
Amaral, E.C.S.	CNEN-Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Azeredo, A.M.G.F.	CNEN-Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Azeredo, R.	Jornal "O Popular", Rua Tomás Edson, quadra 7, CEP 74835-130 Setor Serrinha, Goiânia, Brazil
Balonov, M.A.	Institute of Radiation Hygiene, Mira Street 8, 197101 St. Petersburg, Russian Federation
Barboza, M.M.	CNEN-Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Baskett, R.L.	Lawrence Livermore National Laboratory, Atmospheric Release Advisory Capability (ARAC), 7000 East Avenue, P.O. Box 808, Livermore, California 94551, United States of America
Bøtter-Jensen, L.	Risø National Laboratory, P.O.Box 49, DK 4000 Roskilde, Denmark

Brandão, C.E.	CNEN–Comissão Nacional de Energia Nuclear, Rua General Severiano 90, 22294–040 Botafogo, Rio de Janeiro, Brazil
Carvalho, A.B.	Comissão Nacional de Energia Nuclear (CNEN), Rua General Severiano, 90, 22294–040 Botafogo, Rio de Janeiro, Brazil
Conti, L.F.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Coutinho, M.C.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Crick, M.	International Atomic Energy Agency, Wagramer Strasse 5, P.O.Box 100, A-1400, Vienna
Cunha, P.G.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Curado, P.	Funleide – Fundação Leide Das Neves, Rua 16 A, 792, CEP 77320 Setor Aeroporto, Goiânia, Brazil
Deffner, U.	GSF–Forschungszentrum für Umwelt und Gesundheit, Postfach 1129, D-87578 Neuherberg, Germany
Densow, D.	University of Ulm , Institute of Occupational Medicine, c/o FAW Ulm, P.O. Box 2060, 89010 Ulm, Germany
Doerfel, H.	Kernforschungszentrum Karlsruhe GmbH (KfK), Postfach 3640, D-76021 Karlsruhe 1, Germany
Eckerman, K.	Health and Safety Research Division , Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee 37831, United States of America
Estrada, J.J.S.	CNEN-Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Ferreira, L.M.J.B.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n , Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil

Ferreira, W.	Comissão Nacional de Energia Nuclear (CNEN), Rua 57 n^{o} 142, CEP 74045–060 Centro, Goiânia, Brazil
Finck, R.	Swedish Radiation Protection Institute, S–171 16 Stockholm, Sweden
Godoy, J.M.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
González, A.	International Atomic Energy Agency, Division of Nuclear Safety, Wagramer Strasse 5, P.O.Box 100, A–1400, Vienna, Austria
Gutierrez, J.	Centro de Investigaciones Energeticas , Medioambientales y Tecnologicas (CIEMAT), Instituto de Medio Ambiente, Av. Complutense, 22, 28040 Madrid, Spain
Hacon, S.	Financiadora de Estudos e Projetos (FINEP), Praia do Flamengo, 200, sala 203, CEP 22210–030 Flamengo, Rio de Janeiro, Brazil
Haskell, E.	University of Utah, Radiology Division, 825 North 300 West, Suite 107, Salt Lake City, Utah 84103, United States of America
Hedemann, P.J.	Applied Health Physics Section, Risø National Laboratory, P.O. Box 49, DK–4000 Roskilde, Denmark
Hoe, S.	Ministry of the Interior, Emergency Management Agency, Nuclear Inspectorate, Datavej 16 DK–3460 Birkerod, Denmark
Hunt, J.G.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Jacob, P.	GSF — Forschungszentrum für Umwelt und Gesundheit, Postfach 1129, D–87578 Neuherberg, Germany
Julião, L.Q.C.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Kerns, K.C.	EG&G Energy Measurements, P.O. Box 1912, Las Vegas, Nevada 89125, United States of America

Laurer, G.R. New York University Medical Center,
A.J. Lanza Labs, Long Meadow RD,
Tuxedo, New York 10987,
United States of America

Likhtarev, I. Ukrainian Scientific Center for Radiation Medicine,
Melnikova str. 53, 252050 Kiev 50, Ukraine

Lipsztein, J. CNEN–Instituto de Radioproteção e Dosimetria,
Av. Salvador Allende s/n, Cx.P. 37750,
CEP 22780 Recreio, Rio de Janeiro, Brazil

Lucas, J.N. Health & Ecological Assessment Division,
Lawrence Livermore National Laboratory,
P.O.BOX 818 L–452,
Livermore, California 94550,
United States of America

Luz, L.C.Q.P. Laboratório de Ciências Radiológicas,
Universidade do Estado do Rio de Janeiro (UERJ),
Rua São Francisco Xavier, 524
CEP 20550–013 Maracanã,
Rio de Janeiro, Brazil

Magalhães, M.H. CNEN–Instituto de Radioproteção e Dosimetria,
Av. Salvador Allende s/n, Cx.P. 37750,
CEP 22780 Recreio, Rio de Janeiro, Brazil

Malátová, I. Centre of Radiation Hygiene,
National Institute of Public Health,
Srobarova 48, 100 42 Prague 10, Czech Republic

Melo, D.R. CNEN–Instituto de Radioproteção e Dosimetria,
Av. Salvador Allende s/n, Cx.P. 37750,
CEP 22780 Recreio, Rio de Janeiro, Brazil

Métivier, H. Commissariat à L'Energie Atomique–IPSN,
BP no. 6 , F-92265 Fontenay-aux-Roses, France

Moraes, M.J. Comissão Nacional de Energia Nuclear (CNEN),
Rua General Severiano, 90, CEP 22294–040 Botafogo,
Rio de Janeiro, Brazil

Moreira, M.C.F. CNEN–Instituto de Radioproteção e Dosimetria,
Av. Salvador Allende s/n, Cx.P. 37750,
CEP 22780 Recreio, Rio de Janeiro, Brazil

Mota, H.C. CNEN–Instituto de Radioproteção e Dosimetria,
Av. Salvador Allende s/n, Cx.P. 37750,
CEP 22780 Recreio, Rio de Janeiro, Brazil

Mueller, P.G. U.S. Department of Energy,
DOE Nevada Field Office,
P.O. Box 98518,
Las Vegas, Nevada 89193–8518,
United States of America

Natarajan, A.T. Dept. Radiation Genetics,
State University of Leiden,
Wasse Waarseweg 72,
2333 Al, Leiden, Netherlands

Ney, P.	CNEN–Distrito de Goiânia, Rua 57, 142 Centro, 74045–060 Goiânia, Brazil
Oberhofer, M.	CEC–Joint Research Centre-ISPRA Establishment, Radiation Protection Unit, Edif. 51, I–21020 Ispra, Varese, Italy
Oliveira, A.R.	Laboratório de Ciências Radiológicas, Universidade do Estado do Rio de Janeiro (UERJ), Rua São Francisco Xavier, 524, CEP 20550–013 Maracanã, Rio de Janeiro, Brazil
Oliveira, C.A.N.	CNEN–Comissão Nacional de Energia Nuclear, Rua General Severiano, 90, CEP 22294–040 Botafogo, Rio de Janeiro, Brazil
Paretzke, H.G.	GSF — Forschungszentrum für Umwelt und Gesundheit, Postfach 1129, D–87578 Neuherberg, Germany
Paschoa, A.	Departamento de Física, Pontifícia Universidade Católica (PUC), Rua Marquês de São Vicente, 225, CEP 22453–900 Gávea, Rio de Janeiro, Brazil
Pellerin, P.	ScPri–OMS, 31, Rue De L'ecluse , P.O.Box 35t 78110, Le Vesine, France
Penna Franca, E.	Centro de Ciências da Saúde, Instituto de Biofísica Carlos Chagas Filho, Universidade Federal do Rio de Janeiro (UFRJ), CEP–21949–900 Ilha do Fundão, Rio de Janeiro, Brazil
Peres, S.S.	CNEN–Instituto de Energia Nuclear, Proteção Radiológica, Cidade Universitária, CEP 2186 Ilha do Fundão, Rio de Janeiro, Brazil
Pires do Rio, M.A.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Ramalho, A.T.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Ramos Jr., A.C.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Regulla, D.	GSF— Forschungszentrum für Umwelt und Gesundheit, Postfach 1129, D–87578, Neuherberg, Germany
Robison, W.L.	Health & Ecological Assessment Division,

Robison, W.L.	Health & Ecological Assessment Division, Lawrence Livermore National Laboratory, 7000 East Avenue, P.O. Box 808, Livermore, California 94551, United States of America
Rochedo, E.R.R.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx P.37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Roed, J.	Risø National Laboratory, P.O.Box 49, DK–4000 Roskilde, Denmark
Rossi, A.	Centro Brazileiro de Pesquisas Físicas (CBPF), Rua Dr. Xavier Sigaud, 150, CEP 22290–180 Urca, Rio de Janeiro, Brazil
Sachett, I.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, Cx.P. 37750, CEP 22780 Recreio, Rio de Janeiro, Brazil
Santos, Q.C.B.	Fundação Leide Das Neves (FUNLEIDE), Rua 16 A, 792, CEP 77320 Setor Aeroporto, Goiânia, Brazil
Santos, R.	Comissão Nacional de Energia Nuclear (CNEN), Rua General Severiano, 90, CEP 22294–040 Botafogo, Rio de Janeiro, Brazil
Silva, A.C.	Comissão Nacional de Energia Nuclear (CNEN), Rua General Severiano, 90, 22294–040 Botafogo, Rio de Janeiro, Brazil
Silva, A.J.C.	Comissão Nacional de Energia Nuclear (CNEN), Rua General Severiano, 90, 22294–040 Botafogo, Rio de Janeiro, Brazil
Simpson, A.	Scottish Nuclear Emergency Planning Department, 3 Redwood Crescent Peel Park, East Kilbride 674 5PR, United Kingdom
Sinkko, K.	Finnish Centre for Radiation and Nuclear Safety, P.O. Box 268, FIN–00101 Helsinki, Finland
Sinnaeve, J.	DG XII Radiation Protection Research Action, Commission of the European Communities (CEC), Rue de la Loi 200 (ARTS 3/2), B–1049 Brussels, Belgium
Smetsers, R.C.G.M.	National Institute of Public Health, and Environmental Protection, Laboratory of Radiation Research, P.O. Box 1, 3720 BA Bilthoven, Netherlands
Suarez, R .C.	Calle 18A No. 1414 e/43 y 47, Playa, Ciudad Habana, CP. 11300 AP. 6597, Cuba

Susanna, A. F.	ANPA-DISP, Via Vitalliano Brancati, 48, 00144 Rome, Italy
Thomé, D.	EG&G/EM, P.O. Box 1912 , Las Vegas, Nevada 89125, United States of America
Tranjan, A.	FURNAS Centrais Elétricas, Rua Real Grandeza, 219, CEP 22283–900 Botafogo, Rio de Janeiro, Brazil
Tveten, U.	Institutt for Energiteknikk, P.O. Box 40, N–2007 Kjeller, Norway
Valverde, N.	Laboratório de Ciências Radiológicas, Universidade Estadual do Rio de Janeiro (UERJ), Rua S. Francisco Xavier 524, 20550–013 Maracanã, Rio de Janeiro, Brazil
Veiga, L.H.S.	Comissão Nacional de Energia Nuclear (CNEN), Rua General Severiano, 90, 22294–040 Botafogo, Rio de Janeiro, Brazil
Vianna, M.E.C.M.	CNEN–Instituto de Radioproteção e Dosimetria, Av. Salvador Allende s/n, CEP 22780 Recreio, C.P. 37750, Rio de Janeiro, Brazil
Vinhas, L.	Comissão Nacional de Energia Nuclear (CNEN), Rua General Severiano, 90, 22294–040 Botafogo, Rio de Janeiro, Brazil
Voigt, G.	GSF — Forschungszentrum für Umwelt und Gesundheit, Postfach 1129, D–87578 Neuherberg, Germany
Wieser, A.	GSF — Forschungszentrum für Umwelt und Gesundheit, Postfach 1129, D–87578 Neuherberg, Germany