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INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION

April 4, 2011

The International Commission on Radiological Protection (ICRP) in cooperation with Elsevier, the publishers of the Annals of the ICRP, present this special cost-free release of ICRP *Publication 111* Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency.

ICRP is a registered charity that relies on the sale of publications to help support its ongoing work. However, the cost-free release of this publication is a gesture to aid the Japanese people in recovering from the recent earthquake, tsunami, and accident at the Fukushima Daiichi nuclear power plant. Our thoughts are with those in Japan dealing with the aftermath of these tragic events, and we regret that the recommendations of ICRP *Publication 111* need to be put into active use so soon after having been published.

This special free release of ICRP *Publication 111* is dedicated to those in Japan who have lost so very much.

With deep sympathy, on behalf of ICRP,

Claire Cousins
ICRP Chair

Christopher Clement
ICRP Scientific Secretary

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ICRP Publication 111

Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency

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ELSEVIER

Annals of the ICRP

Published on behalf of the International Commission on Radiological Protection

Aims and Scope

The International Commission on Radiological Protection (ICRP) is the primary body in protection against ionising radiation. ICRP is a registered charity and is thus an independent non-governmental organisation created by the 1928 International Congress of Radiology to advance for the public benefit the science of radiological protection. The ICRP provides recommendations and guidance on protection against the risks associated with ionising radiation, from artificial sources widely used in medicine, general industry and nuclear enterprises, and from naturally occurring sources. These reports and recommendations are published approximately four times each year on behalf of the ICRP as the journal *Annals of the ICRP*. Each issue provides in-depth coverage of a specific subject area.

Subscribers to the journal receive each new report as soon as it appears so that they are kept up to date on the latest developments in this important field. While many subscribers prefer to acquire a complete set of ICRP reports and recommendations, single issues of the journal are also available separately for those individuals and organizations needing a single report covering their own field of interest. Please order through your bookseller, subscription agent, or direct from the publisher.

ICRP is composed of a Main Commission, a Scientific Secretariat, and five standing Committees on: radiation effects, doses from radiation exposure, protection in medicine, the application of ICRP recommendations, and protection of the environment. The Main Commission consists of a Chair and twelve other members. Committees typically comprise 10–15 members. Biologists and medical doctors dominate the current membership; physicists are also well represented.

ICRP uses Working Parties to develop ideas and Task Groups to prepare its reports. A Task Group is usually chaired by an ICRP Committee member and usually contains a number of specialists from outside ICRP. Thus, ICRP is an independent international network of specialists in various fields of radiological protection. At any one time, about one hundred eminent scientists and policy makers are actively involved in the work of ICRP. The Task Groups are assigned the responsibility for drafting documents on various subjects, which are reviewed and finally approved by the Main Commission. These documents are then published as the *Annals of the ICRP*.

The membership of the Task Group during the period of preparation of this report was:

J. Lochard (Chair)
I. Bogdevitch
E. Gallego
P. Hedemann-Jensen
A. McEwan
A. Nisbet
A. Oudiz (2006–2007)
T. Schneider
P. Strand

The corresponding members were:

A. Janssens
T. Lazo
Z. Carr

Annals of the ICRP

ICRP PUBLICATION 111

Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency

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Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency

ICRP Publication 111

Approved by the Commission in October 2008

Abstract–In this report, the Commission provides guidance for the protection of people living in long-term contaminated areas resulting from either a nuclear accident or a radiation emergency. The report considers the effects of such events on the affected population. This includes the pathways of human exposure, the types of exposed populations, and the characteristics of exposures. Although the focus is on radiation protection considerations, the report also recognises the complexity of post-accident situations, which cannot be managed without addressing all the affected domains of daily life, i.e. environmental, health, economic, social, psychological, cultural, ethical, political, etc. The report explains how the 2007 Recommendations apply to this type of existing exposure situation, including consideration of the justification and optimisation of protection strategies, and the introduction and application of a reference level to drive the optimisation process. The report also considers practical aspects of the implementation of protection strategies, both by authorities and the affected population. It emphasises the effectiveness of directly involving the affected population and local professionals in the management of the situation, and the responsibility of authorities at both national and local levels to create the conditions and provide the means favouring the involvement and empowerment of the population. The role of radiation monitoring, health surveillance, and the management of contaminated foodstuffs and other commodities is described in this perspective. The Annex summarises past experience of long-term contaminated areas resulting from radiation emergencies and nuclear accidents, including radiological criteria followed in carrying out remediation measures.

Keywords: Post-accident; Rehabilitation; Optimisation; Reference level; Stakeholder involvement; Radiation monitoring; Health surveillance; Contaminated foodstuffs

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Editorial

AFTER THE EMERGENCY…

This issue of the Annals provides advice on the application of the Commission's 2007 Recommendations (ICRP, 2008) with respect to existing exposure situations. Specifically, it deals with people living in long-term contaminated areas after a nuclear accident or radiation emergency, although many aspects of this advice also apply to other instances of existing exposure situations (e.g. radon in dwellings or workplaces, naturally occurring radioactive material, or contaminated sites resulting from past activities).

In some ways, this report picks up where *Publication 109* 'Application of the Commission's Recommendations for the protection of people in emergency exposure situations' (ICRP, 2009) leaves off, since the situations dealt with in this issue may well have evolved from an earlier emergency exposure situation.

The Task Groups working on these two documents have co-ordinated their efforts so that they give complementary advice of use to radiological protection professionals in the field of emergency and consequence management. This co-operation was vital given that an important aspect of the larger problem is the transition from an emergency exposure situation to an existing exposure situation. Strategies must change from those driven mainly by urgency, with potentially high levels of exposure and predominantly central decisions, to more decentralised strategies which aim to improve living conditions and reduce exposures to as low as reasonably achievable given the circumstances.

One general point that the reader should take from this report is that it emphasises the new approach of the Commission which reinforces that the principle of optimisation of protection (with some type of restriction on individual doses) is absolutely central to the system of protection, and that it is to be applied in a similar way to all exposure situations. Optimisation, aided by the use of reference levels, is essential to the approaches described in this report.

Another important point is that the success of measures taken to control doses to members of the public in existing exposure situations relies heavily on the behaviour of those exposed. This should not be seen as a weakness, but rather a strength that can be exploited through the involvement of key stakeholders; provision of timely, understandable, and practical information; and encouragement of self-protection measures.

Worldwide experience following accidents (both nuclear and non-nuclear) has shown that individuals are often not particularly willing to leave affected areas. In addition, even if restrictions must be put on land uses and lifestyles, in the long term people wish to live life that is as normal as possible. Therefore, whenever possible, a long-term goal should be to rehabilitate areas to allow people to return to their normal habits.

After all, isn't it true that what most people really want is to continue living their lives, and that they are willing and able (sometimes with a little guidance) to help make that happen?

Christopher H. Clement
Scientific Secretary, ICRP

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CONTENTS

PREFACE

At its meeting in Paris in March 2005, the Main Commission of the International Commission on Radiological Protection (ICRP) approved the formation of a new Task Group, reporting to Committee 4, to develop guidance on the implementation of its new Recommendations (ICRP, 2007) for the protection of people living in long-term contaminated areas after a nuclear accident or a radiation emergency.

The terms of reference of the Task Group were to provide guidance on:

- setting reference levels for planning long-term protection strategies;
- implementing optimised protective actions;
- involving stakeholders in radiological protection;
- developing radiation monitoring and health surveillance; and
- managing contaminated commodities.

In developing its guidance, the Task Group was encouraged to co-ordinate with the concurrently approved Task Group in charge of elaborating recommendations on the application of the Commission's Recommendations for the protection of people in emergency exposure situations (ICRP, 2009).

The present report takes account of past experience of the protection of populations living in contaminated areas, particularly in the Commonwealth of Independent States countries affected by the Chernobyl accident, and to a lesser extent to other past accidents and events that resulted in the contamination of large areas. It takes also into account recent methodological and practical developments at international and national levels: the INEX programme of the Committee of Radiation Protection and Public Health of the Nuclear Energy Agency/Organisation for Economic Co-operation and Development (NEA/OECD), the EURANOS Project of the European Commission, the French CODIRPA exercise, the ETHOS Project, and the CORE Programme on post-Chernobyl rehabilitation in Belarus.

The guidance offered by the Task Group is generic, providing a basic framework that can be tailored for specific circumstances. The detailed implementation of the Commission's Recommendations is a matter for the relevant national authorities.

The membership of the Task Group during the period of preparation of this report was:

J. Lochard (Chair)	I. Bogdevitch	E. Gallego
P. Hedemann-Jensen	A. McEwan	A. Nisbet
A. Oudiz (2006–2007)	T. Schneider	P. Strand

The corresponding members were:

A. Janssens	T. Lazo	Z. Carr

The membership of Committee 4 during the period of preparation of this report was:

A. Sugier (Chair)	P. Burns	P. Carboneras
D. Cool	J. Cooper (Vice-Chair)	M. Kai
J-F. Lecomte (Secretary)	H. Liu	J. Lochard
G. Massera	A. McGarry	K. Mrabit
M. Savkin	K-L. Sjöblom	A. Tsela
W. Weiss		

The Task Group met four times:

13–15 February 2006, NEA/OECD, Issy-les-Moulineaux, France
2–4 October 2006, NEA/OECD, Issy-les-Moulineaux, France
16–18 April 2007, NEA/OECD, Paris, France
4–6 February 2008, World Health Organization (WHO), Geneva, Switzerland

The Task Group members wish to thank Peter Schmidt from Wismut GmbH who gave a useful presentation on management of the rehabilitation of areas contaminated by uranium mining and milling activities in the former East Germany, Mikhail Savkin from the Biophysics Institute of Russia for sharing his experience of the management of the long-term consequences of the Chernobyl accident, and Céline Bataille from CEPN-France for her scientific assistance.

The Task Group would also like to thank those organisations and staff that made facilities and support available for its meetings. These include NEA/OECD (Paris) and WHO (Geneva).

The report was adopted by the Commission at its meeting in Buenos Aires, Argentina on 25 October 2008.

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ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2–4).

ICRP, 2009. Application of the Commission's recommendations for the protection of people in emergency exposure situations. ICRP Publication 109. Ann. ICRP 39 (1).

EXECUTIVE SUMMARY

(a) The present report provides guidance on the application of the Commission's Recommendations for the protection of people living in long-term contaminated areas resulting from either a nuclear accident or a radiation emergency. This post-accident rehabilitation situation is considered by the Commission as an 'existing exposure situation'.

(b) The following recommendations are the first to deal with the management of existing exposure situations since publication of the 2007 Recommendations (ICRP, 2007). They complement those made in *Publication 82* (ICRP, 2000), and further develop the role of stakeholders, introduced for the first time by the Commission in this publication. They also take into account the evolution introduced by the 2007 Recommendations from the previous process-based approach of practices and interventions to an approach based on the characteristics of radiation exposure situations. They particularly emphasise the new approach of the Commission, which reinforces the principle of optimisation of protection to be applied in a similar way to all exposure situations with restrictions on individual doses.

(c) Although developed for managing a specific category of existing exposure situation, many recommendations developed in this report are broadly applicable with the necessary adaptations to other existing exposure situations like, for example, radon in dwellings and workplaces, naturally occurring radioactive material, or contaminated sites resulting from past nuclear and industrial activities. This particularly concerns the use of reference levels to plan protection strategies, the role of self-help protective actions complementing the protective actions implemented by authorities, and the accompanying measures to inform the affected individuals.

(d) The transition from an emergency exposure situation to an existing exposure situation is characterised by a change in management, from strategies mainly driven by urgency, with potentially high levels of exposure and predominantly central decisions, to more decentralised strategies aiming to improve living conditions and reduce exposure to as low as reasonably achievable given the circumstances. The decision to allow people who wish to live in contaminated areas to do so is taken by the authorities, and this indicates the beginning of the post-accident rehabilitation phase. Implicit with this decision is the ability to provide people with protection against the potential health consequences of the radiation, and sustainable living conditions, including respectable lifestyles and livelihoods.

(e) Past experience of existing exposure situations resulting from a nuclear accident or a radiological emergency has revealed that all dimensions of the daily life of the inhabitants within the contaminated areas, as well as the social and economic activities, are affected. These are complex situations which cannot be managed with radiation protection considerations alone, and must address all relevant dimensions such as health, environmental, economic, social, psychological, cultural, ethical, political, etc.

(f) In most existing exposure situations affecting the living place of the population, the level of exposure is mainly driven by individual behaviour and is difficult to control at the source. This generally results in a very heterogeneous distribution of exposures, which call for an individual approach for control of the situation. As a consequence, the use of the 'average individual' is not appropriate for the management of exposure in a contaminated area.

(g) Living or working in contaminated areas is considered to represent an existing exposure situation. For such situations, the fundamental protection principles include the justification of implementing protection strategies, and the optimisation of the protection achieved by these strategies. Reference levels are used during the optimisation process to plan protection strategies that would result in estimated residual doses lower than these levels. Dose limits do not apply because existing exposure situations cannot be managed in an a priori fashion.

(h) Protection strategies are made up of a series of protective actions directed at the relevant exposure pathways. The justification and optimisation of protection strategies are an evolution from previous Recommendations, which were focused on justification and optimisation of individual protection measures.

(i) In the case of an existing exposure situation following an emergency exposure situation, justification applies initially to the fundamental decision to be taken by the authorities at the end of the emergency exposure situation to allow people to live permanently in long-term contaminated areas. Such a decision may be accompanied by the setting of a radiation protection criterion above which it is mandatory to relocate the population, and below which inhabitants are allowed to stay subject to certain conditions. Several areas may be defined with relevant conditions according to a graded approach. Secondly, the justification principle applies at the level of decision related to the definition of the protection strategies to be implemented to maintain and possibly improve the radiological situation resulting from the emergency phase.

(j) The responsibility for ensuring an overall benefit to society as well as to individuals when populations are allowed to stay in contaminated areas lies with governments or national authorities. Worldwide experience following nuclear and non-nuclear accidents shows that neither nations nor individuals are very willing to leave affected areas. In general, while authorities may require individuals to leave the affected areas for health reasons in case of excessive residual levels of exposure, wherever possible, they will aim to rehabilitate these areas to allow further human activities.

(k) The principle of optimisation of protection with a restriction on individual dose is central to the system of protection recommended by the Commission for existing exposure situations. Due to its judgemental nature, there is a strong need for transparency of the process. This transparency assumes that all relevant information is provided to the involved parties, and that the traceability of the decision-making process is documented properly, aiming for an informed decision.

(l) Protection strategies have to be prepared by authorities as part of national planning arrangements. These plans should take into account self-help protective actions, including the conditions to allow such actions to be undertaken by the inhabitants, and their results in terms of prospective dose reduction.

Although it is difficult to ask the population to plan in advance for these actions, the Commission recommends authorities to involve key representative stakeholders to participate in the preparation of these plans.

(m) As in most cases in long-term contaminated areas, the level of exposure is driven by individual behaviour; the authorities should facilitate processes to allow inhabitants to define, optimise, and apply their own protective actions if required. A positive aspect is that individuals regain control of their own situation. However, self-help protective actions may be disturbing and their implementation supposes that affected individuals are fully aware of the situation and well informed. It is the government's responsibility to provide good guidance and to provide the means to implement it. Hence the government, or the responsible authority, will need to constantly evaluate the effectiveness of the protection strategy in place, including protective actions carried out at local or individual levels, in order to provide adequate support on how to further improve the situation.

(n) The Commission recommends that reference levels, set in terms of individual annual effective residual dose (mSv/year), should be used in conjunction with the planning and implementation of the optimisation process for exposures in existing exposure situations. The objective is to implement optimised protection strategies, or a progressive range of such strategies, which aim to reduce individual doses below the reference level. During the planning stage, the optimisation process should result in estimated residual doses that are below the reference level. During implementation of the optimisation process, particular attention should be given to reduce individual exposures that may remain above the reference level. However, exposures below the reference level should not be ignored; they should also be assessed to ascertain whether protection is optimised or further protective actions are needed.

(o) The reference level for the optimisation of protection of people living in contaminated areas should be selected in the lower part of the 1–20 mSv/year band recommended in *Publication 103* (ICRP, 2007) for the management of this category of exposure situations. Past experience has demonstrated that a typical value used for constraining the optimisation process in long-term post-accident situations is 1 mSv/year. National authorities may take into account the prevailing circumstances, and also take advantage of the timing of the overall rehabilitation programme to adopt intermediate reference levels to improve the situation progressively.

(p) Reference levels are used both prospectively, for planning of protection strategies (as well as, if necessary, defining derived reference levels for the implementation of some specific protective actions such as, for instance, trade of foodstuffs), and retrospectively as a benchmark for judging the effectiveness of implemented protection strategies.

(q) The fact that exposures have been reduced below the reference level is not a sufficient condition to discontinue protective actions as long as there is room to reduce exposures further in conformity with the optimisation process. The continuation of such actions would probably be a prime mechanism to maintain exposures close or similar to those in normal situations as recommended by the Commission.

(r) The management of an existing exposure situation following a nuclear accident or a radiological emergency relies on the implementation of a more or less complex rehabilitation programme coping with numerous dimensions (social, economic, health, environmental, etc.) according to the level of contamination and its space and time distribution. The implementation of protection strategies is a dynamic process which changes with the evolution of the radiological situation.

(s) It is the responsibility of the authorities, particularly at the regulatory level, to establish the conditions and to implement the means to allow effective engagement of the affected population in the protection strategies and more globally in the rehabilitation programme. Past experience of the management of contaminated areas has demonstrated that the involvement of local professionals and inhabitants in the implementation of protection strategies is important for sustainability of the rehabilitation programme. Mechanisms for engaging with stakeholders are driven by national and cultural characteristics, and should be adapted to the circumstances.

(t) The priority of protection strategies implemented by authorities is to protect people with the highest exposures, and in parallel to reduce all individual exposures associated with the event to as low as reasonably achievable. This implies assessment of the dose distribution, comparison of all doses with the reference level, and subsequent optimisation of protection. Typical strategies to be implemented by the authorities in a post-accident situation are clean-up of buildings, remediation of soils and vegetation, changes in animal husbandry, monitoring of the environment and produce, provision of clean foodstuffs, managing of waste (resulting from clean-up or from unmarketable contaminated goods), provision of information, guidance, instruction and equipment (e.g. for measurements), health surveillance, education of children, information for particular exposed groups and the public at large, etc. Experience has shown that the dissemination of a 'practical radiological protection culture' within all segments of the population, and especially within professionals in charge of the public health and education, is key to the success of protection strategies in the long term.

(u) Typical actions taken by the inhabitants in long-term contaminated areas, called 'self-help protective actions' by the Commission, are those aiming at the characterisation of their own radiological situation, notably their external and internal exposure. These mainly consist of monitoring the radiological quality of their direct environment (ambient dose rates in living areas and contamination of foodstuffs), their own external and internal exposure, and the exposure of the people for whom they have responsibility (e.g. children, elderly), and in adapting their way of life accordingly to reduce their exposure. Authorities should facilitate the setting-up of local forums involving representatives of the affected population and relevant experts (e.g. health, radiation protection, agriculture authorities, etc.). These forums will allow gathering and sharing of information, and favour common assessment of the effectiveness of strategies driven by the populations and the authorities.

(v) In recent years, stakeholder engagement has moved steadily to the forefront of policy decisions. Such engagement is considered by the Commission as key to the development and implementation of radiological protection strategies for most existing exposure situations. The control of radon in dwellings is another typical example. As experience in stakeholder engagement has grown, it has been possible to use many of the lessons learned as a basis for the development of best practice among the radiation protection community. Processes and tools are becoming established that can be generally applied to situations where the views and input of stakeholders are instrumental in improving the quality of protection.

(w) In the case of an existing exposure situation, the Commission recommends that the individuals concerned should receive general information on the exposure situation and the means of reducing their doses. In situations where individual lifestyles are key drivers of the exposure, individual monitoring is an important requirement, coupled with an information programme. Furthermore, given the uncertainties concerning future potential health effects of the exposures received by the population since the emergency phase, it is the responsibility of the authorities to implement a radiation and health surveillance programme.

(x) From the perspective of assessing the evolution of the exposure situation and the effectiveness of the protection strategies, the Commission recommends that a monitoring record system should be established under the responsibility of the relevant authorities. Such records are particularly important for determining potential groups at risk, in conjunction with health surveillance. Furthermore, to allow effective long-term health surveillance of the affected population, the Commission also recommends that health registries should be established for the population residing in the contaminated areas.

(y) The management of contaminated foodstuffs and other commodities produced in areas affected by a nuclear accident or a radiation emergency presents a particularly difficult problem because of issues of market acceptance. Furthermore, maintaining long-term restrictions on the production and consumption of foodstuffs may affect the sustainable development of the contaminated areas, and therefore call for appropriate implementation of the optimisation principle. Reconciling the interests of local farmers, producers, and the local population with those of consumers and the food distribution sector from outside the contaminated territory has to be considered carefully.

(z) The Commission considers that, despite the socio-economic complexity of the management of contaminated foodstuffs, in view of the interests of different stakeholders, protection strategies should be developed to meet the established reference level and optimised at all levels where it is possible to intervene: production, distribution, processing, as well as measures taken for informing consumers and allowing them to make appropriate choices. Derived reference levels expressed in Bq/kg or Bq/L play an important role in this process, in particular for the placing of foodstuffs on the market.

(aa) Commodities other than foodstuffs may be contaminated following a nuclear accident or other radiological emergency. These could include agricultural products such as wood, paper, and oil, or other products recycled from contaminated materials such as scrap metal. The objective again is to reduce exposure to as low as reasonably achievable, taking into account social and economic factors.

(bb) Past experience of long-term contaminated areas resulting from either nuclear tests (Bikini, Maralinga), nuclear accidents (Kyshtym, Palomares, Chernobyl), or a radiological source accident (Goiânia) illustrates the potential importance of ingestion of contaminated foodstuffs several decades after the event at the source of the problems when large rural areas are affected. Management of these foodstuffs to protect the local population against chronic internal exposure and to maintain the viability of local productions is essential. When urban and semi-urban environments are affected, irradiation and inhalation may remain significant exposure pathways for a long period of time. As far as the setting of reference levels for existing exposure situations resulting from nuclear accidents and radiation emergencies is concerned, past experience shows that typical dose values selected by authorities to manage such situations are close or equal to 1 mSv/year, corresponding to the desire to progressively reduce long-term exposure to levels that are close or similar to situations considered 'normal', i.e within the band of constraints set for public exposure in planned situations.

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1. INTRODUCTION

1.1. Background

(1) In *Publication 103*, the International Commission on Radiological Protection (ICRP) described the general principles for the implementation of its system of protection in three different types of exposure situation – planned, emergency, and existing – which replace the previous distinction between practices and interventions (ICRP, 2007, Para. 176):

- planned exposure situations are situations involving the deliberate introduction and operation of sources;
- emergency exposure situations are situations that may occur during the operation of a planned situation, or from a malicious act, or from any other unexpected situation, and require urgent action in order to avoid or reduce undesirable consequences; and
- existing exposure situations are exposure situations that already exist when a decision on control has to be taken, including prolonged exposure situations after emergencies.

(2) The present report provides guidance on the application of the Commission's Recommendations for the protection of people living in long-term contaminated areas resulting from either a nuclear accident or a radiation emergency. This post-accident rehabilitation situation is considered by the Commission as an 'existing exposure situation' (ICRP, 2007, Para. 240).

(3) In the past, the Commission has set out general principles for planning protective actions after an accident. The first guidance was issued in *Publication 40* (ICRP, 1984) but this was confined to short- and medium-term actions. This guidance was then revised and complemented in *Publication 63* (ICRP, 1993) in the light of the 1990 Recommendations (ICRP, 1991). *Publication 82* (ICRP, 2000), on the protection of the public in situations of prolonged radiation exposure, was the first to deal explicitly with application of the Commission's system of radiological protection to controllable radiation exposure due to long-lived radioactive residues in the environment.

(4) The recommendations in this report complement those of *Publication 82* (ICRP, 2000). They further develop the role of stakeholders, recognising that those concerned with this type of situation should be involved and given the opportunity to participate directly in the implementation of protective actions to control their exposure. They also take into account the evolution introduced by the 2007 Recommendations from the previous process-based approach of practices and interventions to an approach based on the characteristics of radiation exposure situations. They particularly emphasise the new approach of the Commission, which reinforces the principle of optimisation of protection to be applied in a similar way to all exposure situations with restrictions on individual doses.

(5) The following recommendations are the first to deal with the management of existing exposure situations since publication of the 2007 Recommendations.

Although developed for managing a specific category of existing exposure situation, many recommendations developed in this report are broadly applicable with the necessary adaptations to other existing exposure situations, such as radon in dwellings or workplaces, naturally occurring radioactive material, or contaminated sites resulting from past nuclear and industrial activities. This particularly concerns the use of reference levels to plan and implement protective actions (Section 3.3), the role of self-help protective actions complementing the protective actions implemented by authorities, and the accompanying measures to inform the affected individuals (Section 4.2).

1.2. Scope

(6) Nuclear accidents and radiation emergencies are managed according to guidance covering short-, medium-, and long-term actions. The most recent guidance related to the management of short- and medium-term actions is provided by ICRP *Publication 109* (ICRP, 2009) on the Application of the Commission's Recommendations for the protection of people in emergency exposure situations. The post-accident rehabilitation situation covered by this report corresponds to the long-term actions that may need to be implemented in the case of a nuclear accident or radiological event resulting in long-term contamination of large inhabited areas.

(7) The transition from an emergency exposure situation to an existing exposure situation is characterised by a change in management from strategies mainly driven by urgency, with potentially high levels of exposure and predominantly central decisions, to more decentralised strategies aiming to improve living conditions and reduce exposures to as low as reasonably achievable given the circumstances. These strategies must take into account the long-term dimension of the situation, and exposed individuals should be directly involved in their own protection. The Commission recommends that this transition should be undertaken in a co-ordinated and fully transparent manner, and agreed and understood by all the affected parties.

(8) The decision to allow people to live in contaminated areas if they wish to do so is taken by the authorities, and this indicates the beginning of the post-accident rehabilitation phase. Implicit with this decision is the ability to provide individuals with protection against the potential health consequences of radiations, and the provision of sustainable living conditions, including respectable lifestyles and livelihoods.

(9) In the case of severe accidents affecting very large areas, the management of the response may need to deal simultaneously with actions relating to its different phases in different geographic areas. Thus, the transition from an emergency exposure situation to an existing exposure situation may occur at different times within the contaminated areas.

1.3. Structure of the report

(10) Chapter 2 considers the effects of a nuclear accident or a radiation emergency on the affected population. This includes the pathways of human exposure, the types

of exposed populations, the characteristics of exposures, and the experience from past events. Chapter 3 discusses the application of the Commission's Recommendations in this type of existing exposure situation, and includes consideration of justification and optimisation of protection strategies, and the introduction and application of reference levels to reduce inequity in individual dose distributions. Chapter 4 considers practical aspects of the implementation of protection strategies, both by authorities and the affected population. Chapter 5 covers radiation monitoring and health surveillance, and Chapter 6 deals with the management of contaminated foodstuffs and other commodities.

(11) Finally, Annex A summarises past experience of long-term contaminated areas resulting from radiation emergencies and nuclear accidents, including the radiological criteria followed in carrying out remediation measures.

1.4. References

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2. LIVING IN CONTAMINATED AREAS

(12) Past experience of existing exposure situations resulting from a nuclear accident or a radiological emergency has revealed that all dimensions of daily life of the inhabitants, as well as social and economic activities, are affected within the contaminated areas. These are complex situations which cannot be managed with radiation protection considerations alone, and must address all relevant dimensions such as health, environmental, economic, social, psychological, cultural, ethical, political, etc. (UNDP, 2002). Although the present recommendations focus on the basic radiation protection principles to be applied to this type of exposure situation, they have been developed taking into account this complexity and the experience gained so far with its management.

2.1. Exposure pathways

(13) The types of existing exposure situation considered in this report are the result of dispersive events that lead to radioactive contamination over relatively extended areas. The pattern of deposition is dependent on the magnitude of the dispersive event, both in terms of activity and energy release, and on prevailing meteorological conditions at the time of the release, particularly the wind direction and any rainfall occurring during the passage of the plume. For an extended release, wind direction can be expected to vary over time. In the longer term, rainfall and weathering will allow penetration of deposited radionuclides into soil and some migration via water pathways or through resuspension. Uptake in plants from soils may vary seasonally. The levels of deposition may also vary greatly from one area to another. After the Chernobyl accident, surface contamination (activity per unit surface area) varied by factors of up to 10–100 within the same village. Generally in the longer term, one or a few radionuclides will dominate as the principal contributors to human exposure.

(14) Following contamination of the environment, several exposure pathways can be distinguished: external exposure due to deposited radionuclides and intake via consumption or inhalation of contaminated material. Radionuclide intake by humans may arise from consumption of vegetables, milk, meat and fish. The transfer to animals will depend on their intake and metabolism of the various radionuclides. Radionuclides deposited directly on plants or in soil may be bound to insoluble particles and be less available for intestinal absorption than radionuclides incorporated in foodstuffs. There may be considerable variation in intakes by the population with time, depending on the season of the year and resulting agricultural practices, and the types of soil and vegetation. Certain areas such as alpine pastures, forests, and upland areas may show longer retention in soils than agricultural areas, and high levels of transfer to particular foods, e.g. berries and mushrooms in forests, may give rise to elevated intakes.

2.2. Characteristics of exposures

(15) In most existing exposure situations affecting the living place of the population, the level of exposure is mainly driven by individual behaviour and is difficult to control at the source. This generally results in a very heterogeneous distribution of exposures. Day-to-day life or work in such a territory inevitably leads to some exposure.

(16) The exposure situation prevailing after the implementation of short- and medium-term actions following a nuclear accident or a radiation emergency will generally show a very broad range of individual exposures, both for the doses already received and for the projected residual doses. The range of individual exposures may be affected by many individually related factors. These include:

- location (of home and work) with respect to the contaminated areas (after clean-up);
- profession or occupation, and therefore time spent and work undertaken in particular areas affected by the contamination; and
- individual habits, particularly the diet of each individual, which could be dependent on her/his socio-economic situation.

Experience has shown that the use of an 'average individual' is not appropriate for the management of exposure in a contaminated area. Large differences may exist between neighbouring villages, within families inside the same village, or even within the same family according to diet, living habits, and occupation. These differences generally result in a highly skewed dose distribution among the affected population. Fig. 2.1 shows the individual dose distribution of children residing in a contaminated district around Chernobyl 20 years after the accident.

(17) Exposure from ingestion of contaminated foodstuffs may result from both chronic and episodic intakes according to the relative importance of locally produced foodstuffs in the diet. As an example, Fig. 2.2 presents the evolution of the whole-body activity associated with an episodic intake of 1000 Bq of ^{137}Cs and with a daily intake of respectively 1 and 10 Bq of ^{137}Cs over 1000 days. For the same total intake, the resulting whole-body activity at the end of the period is significantly different. This illustrates the intrinsically different burden between daily ingestion of contaminated foodstuffs and periodic ingestion. In practice, for people living in contaminated areas, the whole-body activity is resulting from a combination of daily and episodic intakes depending on the origin of foodstuffs and dietary habits.

(18) Twenty years after the Chernobyl accident, typical average daily intake due to ^{137}Cs for an adult in the contaminated areas around Chernobyl is in the range of 10–20 Bq, and additional higher episodic intakes in the range of a few hundred Bq are common due to, for example, the ingestion of wild mushrooms or berries. This results in annual effective doses in the range of 0.1 mSv. However, some poorly informed individuals or those with very particular dietary habits may present daily intakes in the range of 100 to a few hundred Bq. This corresponds to an annual effective dose in the range of 1 to a few mSv.

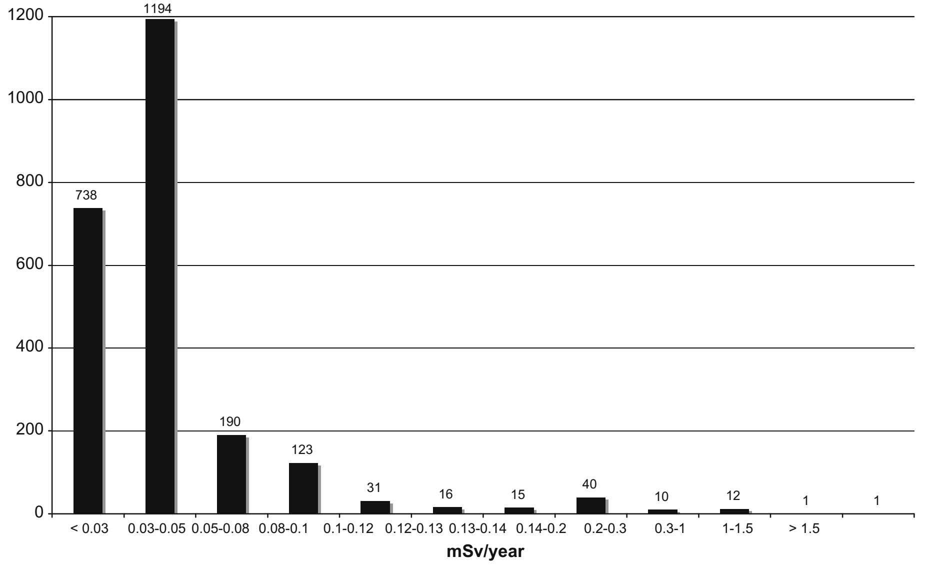

Fig. 2.1. Typical dose distribution from caesium intake of children in the contaminated area around Chernobyl 20 years after the accident.

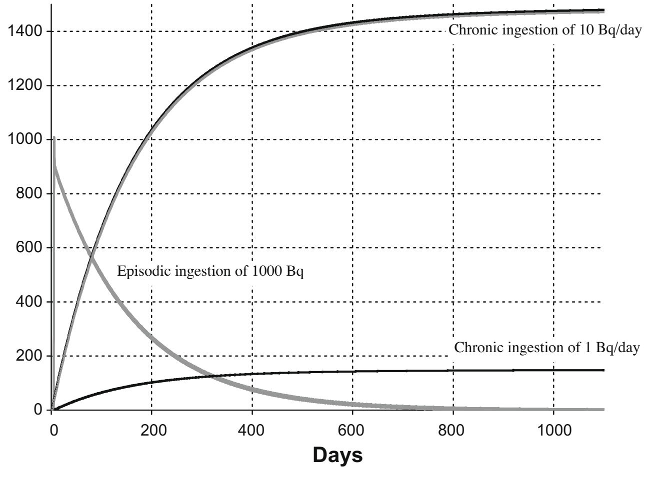

Fig. 2.2. Evolution over a pluri-annual period (1000 days) of whole-body activity (Bq) associated with an episodic intake of 1000 Bq and daily intake of 1 and 10 Bq of ^{137}Cs.

(19) For the sake of controlling exposure in long-term contaminated areas, different exposed groups of populations may need to be considered to assess the overall dose impact in people. The typical population groups generally considered are:

- the 'rural' population: farmers or families with small holdings who are assumed to reside and work in the affected area, and to derive part of their food from locally grown products; and
- the 'urban' population: people who inhabit houses constructed in an affected built-up area, and who may derive foodstuffs from outside the affected area.

In addition, various groups of exposed workers may need to be considered according to the economic activities affected, such as foresters and employees of sawmills in the case of a forest region being impacted. Members of these groups may reside in the contaminated area, or just stay in the area during working hours and reside outside the affected zone. In the latter situation, most of their food will come from non-contaminated areas. If the region attracts tourists, the transient resident population may also need to be considered with its peculiarities.

2.3. Experience from past events

(20) In the past, several nuclear tests (Bikini Island in the Pacific, Maralinga in South Australia, Semipalatinsk in Kazakhstan) and several nuclear accidents (Windscale in the UK, Kyshtym in Russia, Palomares in Spain) have resulted in the contamination of large areas. In addition, the more recent Goiânia radiological source accident in Brazil resulted in the contamination of a limited area. These events have provided significant experience that is of practical value in developing appropriate management approaches to address long-term post-accident radiological issues, and also social, economic, and political issues. However, the Chernobyl accident in Ukraine and other non-radiological emergencies that caused long-term social disruption (flooding, earthquakes, etc.) provided the most important lessons that have served as input for the Commission in its development of these recommendations. More details about the nuclear events can be found in Annex A.

(21) The complexity of the situations resulting from widespread and long-term contamination inevitably generates concerns and anxiety among the affected populations, who could feel helpless. If the experts and professionals in charge of managing the situations use scientific terms, measurement units, and technical procedures, which are difficult to understand by non-specialists, these could contribute to reinforce their feeling of loss of control of the situation.

(22) A commonly observed consequence is the progressive renouncement of individuals to involve themselves in the day-to-day management of such complex situations, and their confrontation with a multitude of questions, which usually remain unanswered. What are the long-term effects of radioactivity on health? Is it possible to protect oneself from the contamination? As a result, inhabitants of contaminated areas often face difficult personal choices concerning their future, and are particularly confronted by the dilemma of whether to leave the place or to stay. Experience shows that it is difficult to answer this dilemma solely on the basis of radiation protection considerations. Many personal aspects enter into the balance; people living in contaminated areas are generally very reluctant to leave their homes, and hope to improve their living conditions. This calls for authorities to not only develop protec-

tive actions but also to favour initiatives to enhance the quality of life of the residents of the areas.

(23) Past experience of long-term contamination has also shown that, in the absence of good knowledge of the radiological situation, affected populations tend to adopt a denial or fatalist attitude. This is a way to further support the situation, which generally results in basic radiation protection advice and actions being neglected, and in increasing exposures. Various projects implemented in the contaminated areas in Belarus (see Annex A) have demonstrated that the direct involvement of inhabitants and local professionals in management of the situation is an effective way to improve the rehabilitation process (Lochard, 2007). This requires regular information on the radiological situation, and the successes and difficulties with implementation of protection strategies. It is the responsibility of the authorities (both national and local) to create the conditions and provide the means favouring the involvement and empowerment of the population. This must be done taking local social and economic living conditions into account to provide individuals with information, thus allowing them to understand and assess their personal situation and to maintain vigilance with the objective to improve their daily life and to protect themselves and their offspring for the future. The aim of the authorities should be to help individuals to regain control of their lives, in which radiation protection against the existing contamination is a factor to add to several other factors affecting the rehabilitation of living conditions.

2.4. References

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3. APPLICATION OF THE COMMISSION'S SYSTEM TO THE PROTECTION OF PEOPLE LIVING IN CONTAMINATED AREAS

(24) Living or working in a contaminated area is considered as an existing exposure situation. For such situations, the fundamental protection principles include the justification of implementing protection strategies and the optimisation of the protection achieved by these strategies. Reference levels are used during the optimisation process to plan protection strategies that would result in estimated residual doses lower than these levels. Dose limits do not apply because existing exposure situations cannot be managed in an a priori fashion.

(25) Protection strategies are made up of a series of protective actions directed at the relevant exposure pathways. The justification and optimisation of protection strategies are an evolution from previous ICRP recommendations, which were focused on justification and optimisation of individual protection measures.

3.1. Justification of protection strategies

(26) The principle of justification is a source-related principle, ensuring that any decision that alters the radiation exposure situation should do more good than harm. In the case of an existing exposure situation following an emergency exposure situation, justification applies initially to the fundamental decision to be taken by the authorities at the end of the emergency exposure situation, to allow people to live permanently in the long-term contaminated areas. Such a decision may be accompanied by the setting of a radiation protection criterion above which it is mandatory to relocate the population, and below which inhabitants are allowed to stay subject to certain conditions. Several areas may be defined with relevant conditions according to a graded approach. This is, for example, the approach adopted by the authorities in the Commonwealth of Independent States countries affected by the Chernobyl accident (see Annex A). Secondly, the justification principle applies at the level of decision related to the definition of the protection strategies to be implemented to maintain and possibly improve the radiological situation resulting from the emergency phase.

(27) For existing exposure situations, protection strategies carried out to reduce individual exposures should achieve sufficient individual or societal benefit to offset the detriment that is caused (ICRP, 2007, Para. 203). However, justification of protection strategies goes far beyond the scope of radiological protection as they may also have various economic, political, environmental, social, and psychological consequences. The social and political value of reducing exposure and limiting inequity in the exposure received by those living in the contaminated areas needs to be included when justification of protection strategies is being carried out. The proper consideration of many of these non-radiological factors may require expertise other than radiological protection, and could dominate decisions on protection strategies (NEA, 2006).

(28) Justification is concerned with the cumulative benefits and impacts of individual protective actions composing the protection strategy. A range of individually

justified actions may be available but may not provide a net benefit when considered as an overall strategy because, for example, collectively they bring too much social disruption for the considered exposed population as a whole, or they are too complex to manage. Conversely, a single protective action may not be justified alone, but may contribute to an overall net benefit when included as part of a protection strategy.

(29) The responsibility for ensuring an overall benefit to society as well as to individuals when populations are allowed to stay in contaminated areas lies with governments or national authorities. Worldwide experience following nuclear and non-nuclear accidents shows that neither nations nor individuals are very willing to leave affected areas. In general, while authorities may require individuals to leave the affected areas for health reasons in the case of excessive residual levels of exposure, they will aim to rehabilitate these areas wherever possible to allow further human activities.

(30) In existing exposure situations, justification should be considered for all protective actions that may be included in a protection strategy: those implemented centrally and locally by authorities, experts, and professionals; and those directly implemented by the exposed individuals as self-help protective actions with the support of the authorities. The protection strategy defined by the authorities should take into account both categories of protective actions, and should enable affected individuals to take self-help initiatives. However, as self-help protective actions are implemented – and thus largely decided – by the inhabitants themselves, they must be properly informed and, if relevant, trained (to use the means and equipment provided by the authorities) in order to take informed decisions concerning their own protection, with a net benefit. The balance to be considered by the individuals includes, on one side, their desire to improve the situation and, on the other side, the 'burden' induced by the implementation of protective actions.

(31) For the management of long term contaminated areas after an accident authorities may consider maintaining some of the protective actions implemented during the emergency exposure situation, and also introducing a whole set of new protective actions. The decision about whether to introduce these new actions will depend on several criteria including the residual individual levels of exposure of the residing population, the feasibility of implementing new actions, and the impact that these actions will have on the quality and sustainability of the living conditions in the territory.

3.2. Optimisation of protection strategies

(32) Implementation of the principle of optimisation of protection is a source-related process, which should ensure the selection of the best protection strategy under the prevailing circumstances, i.e. maximising the margin of good over harm. In order to avoid severely inequitable outcomes of this optimisation procedure, there should be restrictions on the doses or risks to people from a particular source through the application of dose or risk reference levels. Therefore, optimisation involves keeping

exposures as low as reasonably achievable, taking into account economic and societal factors as well as the distribution of doses and benefits resulting from the implementation of the protection strategies.

(33) The process of optimisation of protection is intended for application to those situations for which the implementation of protection strategies has been justified. The principle of optimisation of protection with a restriction on individual dose is central to the system of protection as it applies to existing exposure situations. Due to its judgemental nature, there is a strong need for transparency of the optimisation process. All the data, parameters, assumptions, and values that enter into the process should be presented and defined very clearly. This transparency assumes that all relevant information is provided to the involved parties, and that the traceability of the decision-making process is documented properly, aiming for an informed decision (ICRP, 2006b, Para. 34).

(34) Protection strategies have to be prepared by authorities as part of national planning arrangements. These plans should take self-help protective actions into account, including the conditions to allow such actions to be undertaken by the inhabitants, and their results in terms of prospective dose reduction. Although it is difficult to ask the population to plan in advance for these actions, the Commission recommends that authorities should involve key representative stakeholders to participate in the preparation of these plans.

(35) The case of an existing exposure situation following an emergency exposure situation comprises some specificities. The fact that the population will stay in a contaminated area is, per se, a compromise for them and their family and friends. The optimisation process in such a case faces many specific challenges, notably:

- consumer vs producer interest: to live in a contaminated area supposes that an economic activity is maintained on the spot with local production and trade of goods including foodstuffs. Optimisation strategies should balance the need to protect people against radioactivity and the need for the local economy to exist and to be integrated in the global market;
- local population vs national and international population: the conditions to restore a 'normal' life in the contaminated area suppose solidarity in sharing some disadvantages of the situation between local and non-local populations (mainly related to the movement of goods and people). Optimisation strategies should favour equity, taking into account national regulations and plans as well as international recommendations (e.g. on trade of foodstuffs); and
- the multiple decisions taken by the inhabitants in their day-to-day life: in most cases, the level of exposure is driven by individual behaviour. The authorities should facilitate processes to allow inhabitants to define, optimise, and apply their own protection strategies if required. A positive aspect is that individuals regain control of their own situation. However, self-help protective actions may be disturbing (e.g. pay constant attention to the food one eats, the places one goes, the material one uses... in order to avoid internal and external exposures as much as possible). This supposes that affected individuals are fully aware of the situation and well informed. To support this, various local individuals may also need to

be properly equipped and possibly trained (for the use of equipment provided by the authorities). Authorities should also be prepared to assist segments of the population with particular needs (elderly, mentally handicapped, etc.).

As mentioned previously, taking into account the fact that the predominant pathway in contaminated areas is generally ingestion, protection strategies should be based on controlling this pathway in relation to relevant groups of the population.

(36) Unlike in emergency exposure situations where there is a need to take urgent action, in a post-accident rehabilitation situation, the optimisation process can be implemented step by step, taking the prevailing circumstances into account. Experience has demonstrated that in long-term contaminated areas, it is generally possible to reduce exposures progressively to levels comparable with those in normal situations.

(37) The Commission has introduced the concept of constrained optimisation in order to reduce inequity in the distribution of individual doses. According to *Publication 103* (ICRP, 2007), in the case of existing exposure situations, as for emergency exposure situations, the dose criteria to serve as dose restriction is termed 'reference level' (see Section 3.3).

(38) Optimisation of protection strategies is the process of developing the strategy's form, scale, and duration. The aim is to obtain not only a positive net benefit, but also a maximised net benefit, and decision-aiding techniques can be used to guide the selection of protection strategies and their various elements. The recommendations of the Commission on how to apply these techniques have been provided in *Publication 37* (ICRP, 1983), *Publication 55* (ICRP, 1989), and *Publication 101* (ICRP, 2006), and these recommendations remain valid and are not repeated in detail here. In the process of selecting strategies for protecting people living in contaminated areas, the participation of relevant stakeholders is essential.

(39) The optimisation of protection is a forward-looking iterative process aimed at preventing or reducing future exposures. It takes into account both technical and socio-economic factors, and requires both qualitative and quantitative judgements. The process should be systematic and carefully structured to ensure that all relevant aspects are taken into account. Optimisation is a frame of mind, always questioning whether the best has been done in the prevailing circumstances, and if all that is reasonable has been done to reduce doses (ICRP, 2007, Para. 217). While initially the exposures may be rather high and priority should be given to reducing the highest exposures, continuous efforts need to be made to reduce all exposures with time.

(40) Comparison of justified protection strategies is a key feature of the optimisation process, which must entail careful consideration of the characteristics of the individual exposure distribution within the exposed population. Each group of an exposed population can be described by different attributes as well as by various exposure parameters. The Commission recommends that particular attention should be given to equity in the distribution of exposure among the groups of people concerned.

(41) The best option or strategy is always specific to the exposure situation and represents the best level of protection that can be achieved under the prevailing

circumstances. Therefore, it is not relevant to determine, a priori, a dose level below which the optimisation process should stop (ICRP, 2007, Para. 218). According to the characteristics of the situation, with the presence of relatively long-lived radionuclides in the environment affecting living places, protective actions are expected to be implemented for a long time (up to several tens of years). Optimisation of protection, however, is not minimisation of dose. Optimised protection is the result of an evaluation which carefully balances the detriment from the exposure with the relevant economic and social factors. Thus, the best option is not necessarily the one resulting in the lowest residual dose level for the individuals (ICRP, 2007, Para. 219).

(42) It is the government's responsibility to provide good guidance and the means for its implementation. Hence the government, or the responsible authority, will need to constantly evaluate the effectiveness of the protection strategy in place, including protective actions carried out at local or individual levels, in order to provide adequate support on how to improve the situation further.

3.3. Reference levels to restrict individual exposures

(43) The use of reference levels for the management of both emergency and existing exposure situations is a change for *Publication 103* (ICRP, 2007) compared with *Publication 60* (ICRP, 1991). Some other ICRP publications issued in between introduced the concept of reference level as appropriate to manage prolonged exposure situations, but *Publication 103* clarifies the concept.

(44) The source-related concept of reference level as defined by the Commission in *Publication 103* (ICRP, 2007, Para. 230) represents the level of dose or risk above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimisation of protection should be implemented. It means that protection strategies should be planned and optimised. The chosen value for the reference level will depend upon the prevailing circumstances of the exposure under consideration. The Commission proposed the term 'reference level' for emergency and existing situations (while the term 'dose constraint' is retained for planned exposure situations) to express the fact that a wide range of exposures may characterise the situation, and the optimisation process may apply to initial levels of individual doses above the reference level.

(45) The Commission recommends that reference levels, set in terms of individual annual effective residual dose (mSv/year), should be used in conjunction with the planning and implementation of the optimisation process for exposures in existing exposure situations. The objective is to implement optimised protection strategies, or a progressive range of such strategies, which aim to reduce individual doses below the reference level. During the planning stage, the optimisation process should result in estimated residual doses that are below the reference level. During implementation of the optimisation process, particular attention should be given to reduce individual exposures that may remain above the reference level. Specific groups such as children and pregnant women should also be given particular attention. However, exposures below the reference level should not be ignored; they should also be assessed to

ascertain whether protection is optimised or if further protective actions are needed (ICRP, 2007, Para. 286).

(46) In the case of an existing exposure situation following an emergency exposure situation, the reference level is set at the end of the emergency exposure situation phase, when the decision is taken to allow people to live in the contaminated area. The selected reference level represents a level of dose which is intended not to be exceeded, and to strive to move all individual exposures below this level as low as reasonably achievable, with social and economic factors being taken into account.

(47) The Commission proposed a framework presenting the factors influencing the choice of source-related dose constraints and reference levels (ICRP, 2007, Table 5). In this framework, the Commission introduced three bands of constraints or reference levels according to the characteristics of the exposure situation, taking into account the controllability of the exposure, the benefit from the situation to individuals or society, and the radiological protection measures that would need to be implemented. These measures include the need or not to establish protection strategies as well as to provide information, training, and/or monitoring to exposed individuals. It is the responsibility of regulatory authorities to decide on the legal status of the reference level set to control a given situation.

(48) In the case of an existing exposure situation following an emergency exposure situation, the radiation source is under control but the controllability of the situation may remain difficult and require constant vigilance by the inhabitants in their day-to-day life. This constitutes a burden for the individuals living in contaminated areas and for society as a whole. However, both may find a benefit of continuing to live in the affected areas. Countries generally cannot afford to lose a part of their territory, and most inhabitants generally prefer to stay in their homes rather than to be relocated (voluntarily or not) to non-contaminated areas. As a consequence, when the level of contamination is not too high to prevent sustainable human activities, authorities will preferably implement all the necessary protective measures to allow people to continue to live in contaminated areas instead of abandoning them. These considerations suggest that appropriate reference levels should preferably be chosen in the 1–20 mSv band proposed by the Commission.

(49) The value of the reference level should result from a careful balance of many inter-related factors, including the sustainability of social, economic, and environmental life, and the overall health (WHO, 1948) of the affected populations. The process of selecting the value of the reference level should also be carefully balanced to appropriately include the views of all relevant stakeholders.

(50) As the long-term objective for existing exposure situations is 'to reduce exposures to levels that are close or similar to situations considered as normal' (ICRP, 2007, Para. 288), the Commission recommends that the reference level for the optimisation of protection of people living in contaminated areas should be selected from the lower part of the 1–20 mSv/year band recommended in *Publication 103* for the management of this category of exposure situation. Past experience has demonstrated that a typical value used for constraining the optimisation process in long-term post-accident situations is 1 mSv/year (see Annex A). National authorities may

take into account the prevailing circumstances and also take advantage of the timing of the overall rehabilitation programme to adopt intermediate reference levels to improve the situation progressively .

(51) Reference levels are used both prospectively, for planning of protection strategies (as well as, if necessary, defining derived reference levels for the implementation of some specific protective actions, such as trade of foodstuffs), and retrospectively as a benchmark for judging the effectiveness of implemented protection strategies. A key focus of protective actions should be on exposures above the reference level, whose existence may indicate that the distribution of exposures is not equitable, and will generally suggest that greater weight should be put on the protection of the most exposed groups of people rather than that of the general population.

(52) The use of reference levels in an existing situation is illustrated in Fig. 3.1, which shows the evolution of the distribution of individual doses with time as a result of the implementation of protection strategies. The evolution of the distributions indicates that the number of people in the contaminated areas exceeding the reference level decreases with time as a consequence of the step-by-step optimisation process.

(53) The fact that exposures have been reduced below the reference level is not a sufficient condition to discontinue protective actions as long as there is room for further reduction in exposure in conformity with the optimisation process. The continuation of such actions would probably be a prime mechanism to maintain exposures close or similar to those in normal situations as recommended by the Commission.

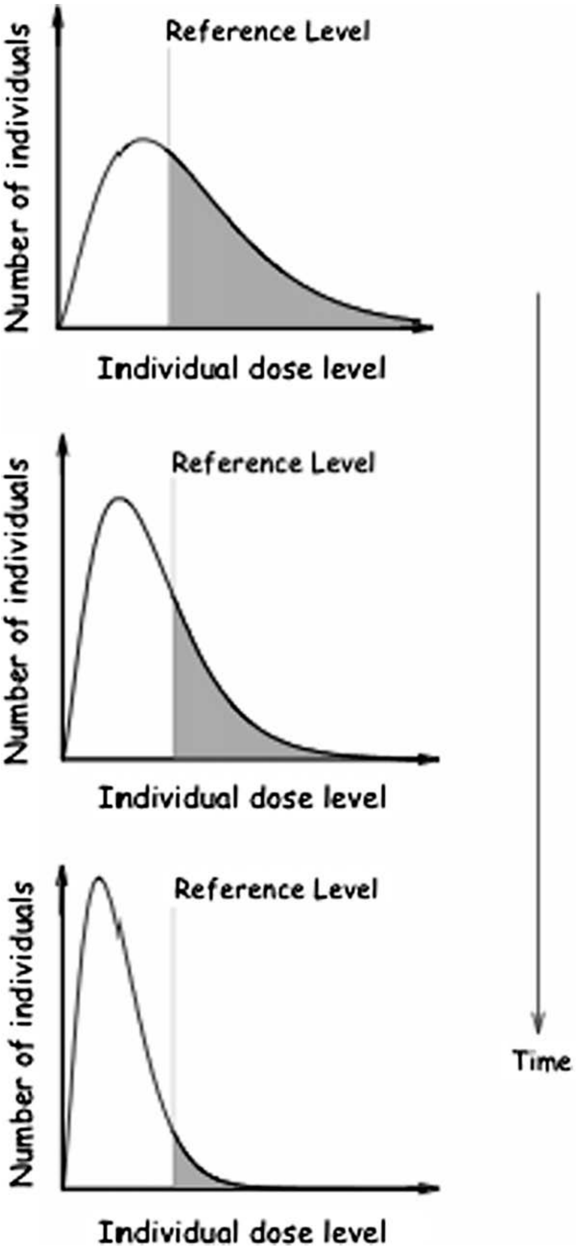

Fig. 3.1. Use of a reference level in an existing exposure situation and evolution of the distribution of individual doses with time as a result of step-by-step implementation of the optimisation process.

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4. IMPLEMENTATION OF PROTECTION STRATEGIES

(54) The management of an existing exposure situation following a nuclear accident or a radiological emergency relies on the implementation of a more or less complex rehabilitation programme coping with numerous dimensions (social, economic, health, environmental, etc.) according to the level of contamination and its space and time distribution. The radiation protection part of this programme is characterised by radiation protection strategies that include actions driven by authorities at national and local levels, and self-help protective actions implemented by the affected population within the framework provided by the authorities. For these strategies to be successful, authorities should provide the necessary infrastructure as well as practical guidance for their implementation. The implementation of protection strategies is a dynamic process, which changes with the evolution of the radiological situation.

(55) It is the responsibility of the authorities, particularly at the regulatory level, to establish the conditions and to implement the means to allow the effective engagement of the affected population in the protection strategies and more globally in the rehabilitation programme. Past experience of the management of contaminated areas has demonstrated that the involvement of local professionals and inhabitants in the implementation of protection strategies is important for the sustainability of the rehabilitation programme (Lochard, 2004). Mechanisms for engaging with stakeholders are driven by national and cultural characteristics and should be adapted to the circumstances.

4.1. Protective actions implemented by authorities

(56) The priority of protection strategies implemented by authorities is to protect people with the highest exposures, and in parallel to reduce all individual exposures associated with the event to as low as reasonably achievable. This implies assessment of the dose distribution, comparison of all doses with the reference level, and subsequent optimisation of protection.

(57) This assessment can often be most effectively supported by radiation monitoring. If measurements are not feasible or sufficiently comprehensive, it is possible to estimate doses likely to be received by the individuals based on local information. In such a situation, the concept of 'representative person' as described in *Publication 101* (ICRP, 2006) may be used, bearing in mind that this concept is most useful for the purpose of prospective assessments of continuing exposure. However, in cases where it is used, the Commission recommends that doses related to the 95–100% percentile should not be discarded.

(58) Once the individual dose distribution is characterised, it is necessary to further investigate the main exposure pathways for the affected population (ambient dose rates, soil contamination, foodstuff contamination, etc.). This will help authorities, in co-operation with the affected population, to decide if they need to pursue protection strategies (decontamination works, foodstuff restrictions, etc.), to modify them

according to the evolution of the radiological situation, or to establish new strategies.

(59) Typical strategies to be implemented by the authorities in a post-accident situation are clean-up of buildings, remediation of soil and vegetation, changes in animal husbandry, monitoring of the environment and produce, provision of clean foodstuffs, waste management (resulting from clean-up or from unmarketable contaminated goods), provision of information, guidance, instruction and equipment (e.g. for measurements), health surveillance, education of children, information for particular exposed groups and the public at large, etc.

(60) Radiological contamination of the environment will evolve with time due to radioactive decay of the radionuclides present, the effect of physical and chemical processes on the distribution of the radionuclides in the environment, and the impact of human activities that may further concentrate or dilute the contamination present in the environment. The long-term dimension of an existing exposure situation therefore calls for step-by-step implementation of protection strategies.

(61) Identification of the highest doses of the distribution should prompt investigation of whether further collective protection strategies can be implemented to protect specific groups of people, or whether the high doses are related to individual habits such that the individuals can be informed and empowered to implement their own strategies.

(62) From this perspective, authorities will have to set up infrastructures to support the implementation of all protection strategies, including self-help strategies implemented by the affected population. The dissemination of a 'practical radiological protection culture' within all segments of the population, and especially within professionals in charge of public health and education, is also an important element of the strategy. Experience has shown that the development of such an infrastructure is based on three key pillars:

- a radiation monitoring system, by which the radiological quality of the environment can be evaluated, levels of internal and external exposure of people assessed, and allowing the affected individuals direct access to this information (see Section 5.1);
- a health surveillance strategy to follow the health status of the affected population. This calls for a system based on regular clinical investigations as well as the development of registries to monitor important indices in public health in relation to the level of individual exposure. Such a system should allow the identification of any changes in the health status of the population that could occur, and investigate whether these changes could be related to radiation or other factors (in relation with the early phase or long-term exposure) – see Section 5.2; and
- the transmission of practical knowledge within the population about the control of the radiological situation to current and future generations based on the dissemination of monitoring results, for example through the education system.

4.2. Protective actions implemented by the affected population

(63) In the case of a radiological accident, the affected population will be confronted with new problems and new preoccupations. Each individual will have questions regarding radioactivity and its effects: how is the environment contaminated, how is one exposed, and at what time, particularly, is one contaminated? Individuals will also wonder how to face this new situation, and what to do to reduce their current and future exposure to as low as reasonably achievable.

(64) The engagement of the affected population in the development and implementation of actions defined by authorities will be key to their effectiveness. In addition, however, many actions to manage exposures will be driven by individual behaviour. These will also require a framework of support from the authorities in order to be effective and sustainable.

(65) Typical actions taken by the inhabitants in this framework, called 'self-help protective actions' by the Commission, are those aiming to characterise their own radiological situation, notably their external and internal exposure. These mainly consist of monitoring the radiological quality of their direct environment (ambient dose rates in living places and contamination of foodstuffs), their own external and internal exposure, and the exposure of the people for whom they have responsibility (e.g. children, elderly), and adapting their way of life accordingly to reduce their exposure.

(66) As far as the evaluation of external exposure is concerned, inhabitants may better manage the situation by establishing local mapping of their living places (e.g. house, garden, working place, leisure areas). They can then identify places where the higher ambient dose rates are registered and/or those contributing significantly to the external dose according to the time spent in these places. In both cases, it is possible to try to minimise, as far as possible, time spent in these places.

(67) As far as the evaluation of internal exposure is concerned, inhabitants can act according to the radiological quality of the foodstuffs consumed each day. This supposes that they have access to the measurements of local products. Based on the results of these measurements, they can classify foodstuffs according to their sensitivity to radioactivity, and identify products that are usually more contaminated than others (e.g. mushrooms are much more sensitive to radioactive contamination than vegetables and fruits). In this context, they can adapt their dietary habits to reduce the ingested fraction of contaminated foodstuffs.

(68) In rural zones, a significant part of the affected population may own a private garden. As above, the first step may involve the measurement of radiological quality of the grown foodstuffs. According to the results, they will have to identify how to reduce the contamination of their products by selection of those which are less sensitive to radioactivity, identification of the less contaminated areas in the garden, use of agricultural techniques to limit transfer of radionuclides from soil to plants, etc.

(69) Beyond their contribution to individual exposure, self-help protective actions can also concern management of the radioactive contamination of the environment.

From that perspective, the affected population should take care to adopt protective actions that would avoid reconcentration of radioactivity in their local areas; particular attention may have to be paid to the management of radioactive house waste, such as ashes from fireplaces in rural areas.

(70) As mentioned above, authorities should facilitate the implementation of protection strategies by the inhabitants. They should provide existing results of measurements, information and training to help people to understand and manage their radiological situation, and monitoring equipment (e.g. making the equipment available through local authority offices or doctors or pharmacies who are trained to take measurements). Furthermore, they should ensure regular whole-body measurements of the affected population so that people can evaluate the efficiency of changes in their diet.

(71) Authorities should facilitate the setting-up of local forums involving representatives of the affected population and relevant experts (e.g. health, radiation protection, agriculture authorities, etc). These forums will allow gathering and sharing of information, and favour a common assessment of the effectiveness of strategies driven by the population, and the authorities.

(72) In recent years, stakeholder engagement has moved steadily to the forefront of policy decisions. Such engagement is considered by the Commission to be key to the development and implementation of radiological protection strategies for most existing exposure situations. The control of radon in dwellings is another typical example. As experience in stakeholder engagement has grown, it has been possible to use many of the lessons learned as a basis for the development of best practice among the radiation protection community. Processes and tools are becoming established that can be generally applied to situations where the views and input of stakeholders are instrumental to improving the quality of protection.

4.3. References

ICRP, 2006. Assessing dose of the representative person for the purpose of radiation protection of the public. ICRP Publication 101 – Part 1. Ann. ICRP 36 (2).

Lochard, J., 2004. Living in contaminated territories: a lesson in stakeholder involvement. In: Current Trends in Radiation Protection. EDP Sciences, pp. 211–220.

5. RADIATION MONITORING AND HEALTH SURVEILLANCE

(73) As recommended by the Commission in the case of an existing exposure situation, the individuals concerned should receive general information on the exposure situation and the means of reducing their doses (ICRP, 2007, Table 5). In situations where individual lifestyles are key drivers of the exposure, individual monitoring is an important requirement, coupled with an information programme. Furthermore, given the uncertainties concerning future potential health effects of the exposures received by the population since the emergency phase, it is the responsibility of the authorities to implement a radiation and health surveillance programme.

5.1. Radiation monitoring

(74) In a situation of long-term contamination, it is essential to establish a radiation monitoring system allowing follow-up of the radiological situation and the implementation of adequate protection strategies. The key objective of monitoring systems is to assess current levels of human exposure (both external and internal) and environmental levels of contamination, and to allow the prediction of their evolution in the future. In practice, this supposes a radiation monitoring system providing measurements of ambient dose rates, concentrations of radionuclides in foodstuffs and the environment, and whole-body contamination of individuals.

(75) The effectiveness of the monitoring system relies on its ability to cope with the specificities of the local affected territory. This allows identification of population groups receiving elevated doses and better orientation of radiation protection strategies. For this purpose, a key issue is to take advantage of radiological competence at the local level in combination with the national system. Furthermore, the existence of validated measurements from different origins – authorities, expert bodies, local and national laboratories (non-governmental organisations, private institutes, universities, local stakeholders, nuclear installations, etc.) – allows a better understanding of the local radiological situation and favours confidence in the measurements among the affected population. In this regard, all parties providing measurements should be subject to appropriate quality assurance requirements.

(76) The monitoring system should be designed to provide regularly updated information to authorities and other concerned parties, and to allow extended coverage of the affected territory over the long term. From the perspective of assessing evolution of the exposure situation and the effectiveness of the protection strategies, the Commission recommends that a monitoring record system should be established by the relevant authorities having responsibility. Such records are particularly important for determining potential groups at risk, in conjunction with health surveillance. The sustainability of such a system will require the establishment of continued maintenance and training programmes by national and local authorities.

5.2. Health surveillance

(77) Following a nuclear accident or a radiation emergency, the exposed population should have had an initial medical evaluation. The first step of this evaluation is a census of the affected individuals, possibly with an early dose assessment. In addition, regardless of the level of dose, the affected population should also have been supplied with accurate and appropriate information regarding their level of exposure and potential type of risk.

(78) Taking this background into account, long-term health surveillance programmes will have to cover the following objectives (WHO, 2006):

- the follow-up of persons who have received exposures that have resulted in clinically significant deterministic effects (e.g. skin burns, cataracts, etc.) or sufficiently high levels of exposure to justify preventive surveillance;
- the 'medical monitoring' of the general population, which consists of investigating for potential adverse effects (mainly incidence of radiation-induced cancers). A subcategory of medical monitoring is the follow-up of potentially 'sensitive subgroups' (e.g. children, pregnant women); and
- 'epidemiological' studies.

(79) Medical monitoring refers to screening of the entire affected population in order to detect specific preclinical disease with the purpose of delaying or preventing the development of disease in those individuals. The first step is to justify and delineate the extent of the programme based on consideration of a number of factors. For instance, the following characteristics are of prime importance: the exposure of concern (e.g. its certainty, dose, and temporal relationship of exposure to observation); the disease of interest (e.g. its natural history and prevalence in the population); the characteristics of available screening tests (e.g. their effectiveness, sensitivity, and specificity); the potential for the tests used to cause harm themselves; the potential for action when test results are positive (e.g. the availability of and risks from follow-up evaluation); whether there is evidence that an intervention can improve clinical outcome; and the latency period between radiation exposure and the development of a clinically detectable effect. Beyond the responsibility of public health authorities to preventively monitor the affected population, another important role of medical surveillance is the reassurance given to the population in response to its concerns regarding the potential health impacts of the situation.

(80) According to WHO definitions (WHO, 2006), the aims of epidemiological studies from a long-term perspective are to:

- identify adverse health effects in an at-risk group and determine whether the risk of such effects is greater than that for a comparable non-exposed group of individuals;
- determine whether the increased risks that may be identified are statistically associated with the exposure;
- determine whether the increased observed risk is related to or influenced by other factors associated with or independent of the exposure, such as tobacco smoking and radon; and

- add to the scientific knowledge base, which can then be used to derive and refine risk estimates, and evaluate the efficiency of protective actions that have been implemented or develop new actions.

(81) In practice, epidemiological studies will be adjusted and implemented according to the following considerations: size and composition of the studied population, magnitude and distribution of radiation exposure, accuracy of exposure measurements, disease identification and associated background rate, and availability of information on other risk factors that might affect the outcome. To allow effective long-term health surveillance of the affected population, the Commission recommends that health registries should be established for the population residing in the contaminated areas.

5.3. References

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2–4).

WHO, 2006. Health Effects of the Chernobyl Accident and Special Health Care Programmes. In: Bennett, B., Repacholi, M., Carr, Z. (Eds.), Report of the UN Chernobyl Forum, Expert Group ‘Health’. WHO Press, Geneva, p. 160.

6. MANAGEMENT OF CONTAMINATED FOODSTUFFS AND OTHER COMMODITIES

(82) The management of contaminated foodstuffs and other commodities produced in areas affected by a nuclear accident or a radiation emergency has been addressed previously by the Commission. In *Publication 104* (ICRP, 2007), the Commission recognised that 'this type of situation presents a particularly difficult problem' because of 'issues of market acceptance'. Furthermore, maintaining long-term restrictions on the production and consumption of foodstuffs may affect the sustainable development of the affected areas, and therefore calls for appropriate implementation of the optimisation principle. Reconciling the interests of local farmers, producers, and the local population with those of consumers and the food distribution sector from outside the contaminated territory has to be considered carefully. Determining optimal protection strategies for contaminated foodstuffs may be perceived differently for the population living inside the contaminated territory than for those living outside.

(83) Reducing exposure from the ingestion of foodstuffs produced in long-term contaminated areas to levels as low as reasonably achievable, taking economic and social conditions into account, may involve the implementation of complex protection strategies. The radiological quality of foodstuffs can be managed by many protective actions aimed at reducing the transfer of radionuclides in the foodchain from farm to fork (Nisbet et al., 2006). These protective actions include, for example, the physical and chemical treatment of soils, changes in husbandry practices, provision of feed additives to livestock, selection of alternative land uses, and industrial-scale food processing to remove contamination. The actions selected will depend on the physical and chemical properties of the radionuclides released, season of the year, and the types of land use affected. Whenever possible, protective actions should be implemented so that restrictions on local produce can be avoided. There may be situations where a sustainable agricultural economy is not possible without placing contaminated food on the market. As such foods will be subject to market forces, this will necessitate an effective communication strategy to overcome the negative reactions from consumers outside the contaminated areas.

(84) For management of the radiological quality of foodstuffs in a country with a contaminated territory, relevant stakeholders (authorities, farmers' unions, food industry, food distribution, consumer non-governmental organisations, etc.) and representatives of the general population should be involved in deciding whether individual preferences of the consumers should outweigh the need to maintain agricultural production, rehabilitation of rural areas, and a decent living for the affected local community. A thorough debate at national level is necessary to achieve a certain degree of solidarity within the country.

6.1. Management inside the contaminated areas

(85) A fraction of the diet of the local population may include local agricultural produce, food from private gardens, and food gathered from the wild (e.g. berries,

mushrooms, game). The relative importance of local produce depends on the characteristics of the region, as well as on traditions or habits. To some extent, such habits may be influenced by a preference for food that is less contaminated, or as a result of the availability of food from non-contaminated areas. The local population may also be in a position to manage its intake of radionuclides by avoiding or reducing consumption of products with higher levels of contamination. Furthermore, more sensitive groups of the population or those perceived to deserve special protection (e.g. children, pregnant or breastfeeding women, people with poor health) may be advised to avoid or reduce consumption of certain types of food with higher levels of contamination.

(86) In order to help the local population to control foodstuffs, authorities should provide relevant information and set contamination criteria based on directly measurable levels of contamination (expressed in Bq/kg or Bq/L), taking into account the proportion of locally produced food in the diet. Guideline levels have been developed by the Codex Alimentarius Commission for use in international trade (FAO/WHO, 2006). These levels are based on a dose level of 1 mSv/year assuming that a maximum of 10% of the diet consists of contaminated food. The assumption that 10% of the diet is contaminated may not be valid for some local communities, hence the contamination criteria for foodstuffs may be set below the Codex guideline levels. Conversely, if the contamination only affects a few categories of foodstuffs, the contamination criteria may be set to higher values. Higher contamination criteria may also be set to preserve local production, which may be deeply embedded in traditions or which may be essential to the economy of the entire community.

(87) Disruption to the local economy through the placement of restrictions on the sale of contaminated foodstuffs, the loss of market share as a result of consumer preferences, or through the provision of uncontaminated food may not be warranted in terms of a benefit in dose reduction. Such decisions must be taken in close cooperation with the local stakeholders, as was the case in Norway with reindeer meat produced by the Sami population after the Chernobyl accident (Skuterud et al., 2005). The contamination criteria for foodstuffs finally selected indirectly represents a level of individual dose which is not intended to be exceeded, and the long-term objective should be to reduce this level to as low as reasonably achievable, with social and economic factors taken into account. From this perspective, contamination criteria may be reduced step by step to take the progressive improvement of the situation into account.

6.2. Management of exportations outside the contaminated areas

(88) Protection of populations living outside contaminated areas is mainly driven by the control of trade. Consumers from non-affected areas generally expect uncontaminated foodstuffs to be placed on the market. However, this situation may not always be achievable. First, the interests of the affected population living in the contaminated areas need to be considered, as it may be important to maintain some form of agricultural production there. Furthermore, there is also an intrinsic difficulty in ensuring that radiological control will cover all foodstuffs everywhere

and at all points in time. For these reasons, foodstuffs coming from outside the contaminated areas may contain some contamination, even though it is well below the contamination criteria.

(89) The placement of contaminated foodstuffs on the market may be governed by the Codex guideline levels for use in international trade, which apply to food contaminated following a nuclear or radiation emergency (including both accidents and malevolent actions) for an indefinite period. According to the Codex Alimentarius Commission, food should be considered as safe for human consumption when its levels of radionuclides do not exceed the corresponding guideline levels. When the guideline levels are exceeded, national governments decide whether, and under what circumstances, the foodstuffs should be distributed within their own territory or jurisdiction. The Commission recognises that once food is placed on the market, it is very difficult to manage doses and consequently to optimise them, since any action in the distribution process of food may merely shift contamination from one section of the population to another. This may promptly lead to situations which are regarded as unethical. Even the free supply of such food as humanitarian aid in regions affected by famine would be perceived as such by the beneficiaries. Bearing market forces in mind, these considerations call for investigating all possible actions to improve the radiological quality of foodstuffs before placement on the market.

(90) The restoration and maintenance of consumer confidence is of prime importance in the management of contaminated foodstuffs. Traceability of food is an important factor in consumer preferences. The Commission views the mention of the region of origin on foodstuff labels as a sufficient indicator for marketing purposes. However, the management of market mechanisms is beyond the scope of the Commission's recommendations.

(91) The Commission considers that, despite the socio-economic complexity of the management of contaminated foodstuffs in view of the interests of different stakeholders, protection strategies should be developed to meet the established reference level, and the strategy should be further optimised at all levels where it is possible to intervene, e.g. production, distribution, processing, as well as measures taken for informing consumers and allowing them to make appropriate choices. Derived reference levels expressed in Bq/kg or Bq/L play an important role in this process, in particular for the placement of foodstuffs on the market.

6.3. Management of other commodities

(92) Commodities other than foodstuffs may be contaminated following a nuclear accident or other radiation emergency. These could include agricultural products such as wood, paper, and oil, or other products recycled from contaminated materials such as scrap metal. The objective again is to reduce exposure to as low as reasonably achievable, taking social and economic factors into account.

(93) The Commission recommends the development of optimisation strategies, including the prevention of contamination (e.g. by substitutes whenever possible and relevant, taking into account that agriculture in contaminated areas may be deliberately reoriented towards non-food products), and management of contami-

nated commodities. Such contaminated commodities can be traded and used with or without conditions. Relevant contamination criteria for foodstuffs should be determined depending on the intended use of the commodities and the conditions for trade or use.

(94) The contamination levels for the use of contaminated commodities inside the contaminated areas should be derived from the annual dose reference level on the basis of realistic exposure scenarios. Authorities may fix binding or recommended conditions for use.

(95) Trade of contaminated commodities or consumer products manufactured with contaminated material outside the contaminated territory should be in accordance with the rules or recommendations for international trade. Nevertheless, there could be situations in which provision is made for trading contaminated commodities subject to explicit provisions negotiated with the recipient, and agreed with the relevant stakeholders, in particular the regulatory bodies of the exporting and importing countries. International bodies have recommended numerical values for the use or trade of contaminated commodities (e.g. after the dismantling of a nuclear facility); these can be used as benchmarks by the national authorities to set relevant contamination criteria (IAEA, 2005).

6.4. References

FAO/WHO Codex Alimentarius Commission, 2006. Codex Guideline Levels for Radionuclides in Foods Contaminated Following a Nuclear or a Radiological Emergency for Use in International Trade. CAC/GL 5-2006.

IAEA, 2005. Safety Guide No. RS-G-1.7. Application of the Concepts of Exclusion, Exemption and Clearance. International Atomic Energy Agency, Vienna.

ICRP, 2007. Scope of radiological protection control measures. ICRP Publication 104. Ann. ICRP 37 (5).

Nisbet, A.F., Rice, H., Jones, A., et al., 2006. Generic Handbook for Assisting in the Management of Contaminated Food Production Systems in Europe Following a Radiological Emergency. EURANOS (CAT1)-TN(06)-06. Available at: http://www.euranos.fzk.de.

Skuterud, L., Gaare, E., Eikelman, M., Hove, K., Steinnes, E., 2005. Chernobyl radioactivity persists in reindeer. J. Environ. Radioact. 83, 231–252.

ANNEX A. HISTORICAL EXPERIENCE OF LONG-TERM CONTAMINATED AREAS

A.1. Introduction

(A 1) This annex briefly describes a series of past experiences with long-term contaminated areas resulting from either nuclear tests (Bikini, Maralinga), nuclear accidents (Kyshtym, Palomares, Chernobyl), or a radiological source accident (Goiânia). These experiences are presented in chronological order. Beyond the long-term feature of the contamination, which is common to all, each event illustrates different aspects developed in the present report.

(A 2) The Bikini and Maralinga experiences are not, strictly speaking, prolonged exposure situations since the inhabitants were evacuated prior to the events that led to long-term contamination of their habitat, and no individual now lives permanently in these places although a few people came back for a few years. The options envisaged or effectively implemented to restore the contaminated sites illustrate the predominant exposure pathways and the type of protective actions that may be necessary to maintain exposure to as low as reasonably achievable. It is interesting to note the importance of ingestion of contaminated foodstuffs several decades after the events, particularly in the case of Bikini.

(A 3) The long-term existing exposure situations resulting from the Kyshtym and Chernobyl accidents are, without doubt, the most representative of the types of situation aimed at by the present recommendations. The information concerning management of the Kyshtym accident is relatively poor, but the spread of contamination in space and time is fairly representative of potential large-scale nuclear accidents. The long-term consequences of the Chernobyl accident, both in the Commonwealth of Independent States countries and in Western Europe, have deeply affected the living conditions of millions of inhabitants of the contaminated areas. In all countries, the main concern has been with the management of foodstuffs to protect the local population against chronic internal exposure and to maintain the viability of local productions.

(A 4) Neither the Palomares nor the Goiânia accident can be considered as very representative of the existing exposure situations dealt with in this report because of the relatively limited size of the affected areas and the number of individuals directly concerned. However, they illustrate the type of protective actions to be implemented to control exposure in an urban and semi-urban environment when external irradiation and inhalation are significant exposure pathways.

(A 5) As far as the setting of reference levels for existing exposure situations resulting from nuclear accidents and radiation emergencies is concerned, past experience demonstrates that typical dose values selected by authorities to manage such situations are close or equal to 1 mSv/year, corresponding to the desire to progressively reduce long-term exposure to levels that are close or similar to situations considered 'normal', i.e within the band of constraints set for public exposure in planned situations.

A.2. Bikini

(A 6) Between 1946 and 1958, Bikini Atoll was used for atmospheric tests of nuclear weapons. It was the site of 23 of the 66 underwater, ground-level, and above-ground tests conducted in the Marshall Islands by the USA. As a result of the above-ground tests, the land surfaces and the lagoon became extensively contaminated with radionuclides, of which ^{137}Cs subsequently proved to be the most radiologically important.

(A 7) Prior to the first nuclear test in 1946, the 167 Bikinians were evacuated to neighbouring islands; however, some of them returned in the late 1960s and early 1970s after a preliminary radiological survey of the atoll. Measurements carried out between 1975 and 1978, however, revealed that the ^{137}Cs body contents of the resettled people had increased by factors of approximately 10 since their return. This increase was attributed to high caesium uptake from the soil by coconut trees, producing high caesium concentrations in the coconut milk and flesh consumed by the Bikini islanders; as such, in 1978, the population was relocated again. Scientific studies of the radiological conditions at Bikini Atoll have continued, but the population has not been able to return to date.

(A 8) It is considered that, without remedial action or restrictions on their behaviour, returnees to Bikini Atoll would, on average, receive an annual dose of 4 mSv from the remaining contamination. The highest plausible dose to people who might consume only locally grown foods rather than the more typical mix of local and imported foods is estimated to be approximately 15 mSv/year. The projected doses are largely from ^{137}Cs in foods and the soil. With regard to the other radionuclides still present at significant levels, ^{90}Sr uptake in foods is low because of strong competition from high levels of (chemically similar) calcium, while plutonium and americium isotopes are largely 'trapped' in lagoon sediments, with uptake into fish and other forms of seafood being extremely low.

(A 9) In radiological protection terms, the contamination of Bikini Atoll represents a potential existing exposure situation in the sense that the population was allowed to return to live permanently on the island. A possible protective action to allow this return is soil removal in residential areas and potassium treatment of the existing soil in crop-growing areas. Soil removal would reduce doses from external exposure, and from inhalation and inadvertent ingestion of soil in the areas where islanders spend most time.

(A 10) Potassium treatment would reduce doses from intakes of caesium in food; the main contributor to the overall projected doses. On the basis of extensive trials, it has been estimated that a programme of potassium treatment, repeated every 4–5 years, would reduce the concentration of ^{137}Cs in typical Bikini foods to well below the FAO/WHO Codex Alimentarius guidelines for international trade in foodstuffs. Projected doses would be reduced to approximately 0.4 mSv/year from the normal mix of local and imported foods, or 1.2 mSv/year from a diet of exclusively local produce.

(A 11) An alternative option would be to remove the topsoil from the crop-growing areas as well as the residential areas. This would undoubtedly be effective in reducing exposures, perhaps even more than the potassium treatment. However, it would generate very large volumes of soil requiring safe disposal. Furthermore, replacement soil would need to be imported. The financial, environmental, and social costs of this option would probably be much greater than the first option, and deserve to be evaluated in a proper optimisation process.

A.3. Maralinga

(A 12) British nuclear tests occurred between 1955 and 1963 at the Maralinga site in South Australia. A total of seven major nuclear tests were performed. Prior to selection, the Maralinga site was inhabited by Aboriginal people. Many were relocated to a new settlement at Yulata, and attempts were made to curtail access to the Maralinga site. These were often unsuccessful.

(A 13) Australian authorities established criteria in 1990 for the rehabilitation of former British nuclear test sites in Australia. At two of these sites, Emu and the Monte Bello Islands, there was little need for remediation. However, at Maralinga, several locations were contaminated with plutonium that had been dispersed locally by the explosions.

(A 14) Following extensive experimental studies, it was established that the inhalation of plutonium-contaminated dust by a critical group of Aborigines, living a semi-traditional lifestyle, was the dominant pathway for exposure in most cases. A second important pathway was the incorporation of plutonium, by way of wound contamination, in areas where many plutonium-contaminated fragments or particles were found. The general criterion for the clean-up was to undertake remedial measures to ensure that annual effective doses to the critical group under conditions of full-time occupancy should not exceed 5 mSv, which was the international individual dose limit for practices at that time. The Maralinga clean-up began with site preparations at the beginning of 1996, and took approximately 4 years.

(A 15) At the most extensively contaminated Taranaki site, soil from areas where ^{241}Am exceeded 40 kBq/m^2 was removed, with a restriction on land use which prohibited camping but allowed access for hunting or transit. This figure was based on observations of the likely proportion of time to be spent in the area on allowed activities. At three smaller contaminated sites, which remain outside the area of restricted land use, clean-up levels were required to be more stringent than for Taranaki. Approximately 2.3 km^2 of soil were removed from the most contaminated areas. The removed soil was buried in large excavated trenches adjacent to the soil-removal areas and covered with 5 m of uncontaminated rock and soil.

(A 16) An outer boundary, marked by heavy-duty galvanised steel posts at 50-m intervals, warns that camping is not permitted within the area. These warning signs generally follow the road system and contain all areas where continual occupancy could lead to doses in excess of 5 mSv/year.

A.4. Kyshtym

(A 17) In September 1957, a major accident occurred at the Chelyabinsk-40 military plutonium production facility near Kyshtym in the southern Ural mountains of the former Soviet Union. The facility, built in 1953, had a number of underground steel storage tanks equipped with cooling systems to store high-level waste so that it would not be dumped in the River Techa. These high-level wastes overheated when the cooling system failed. The heat build-up resulted in evaporation of the coolant water, which allowed the sediment to heat further and dry. The chemicals in the tank exploded on 29 September 1957 with an explosive power of 70–100 tons of TNT, which hurled the 2.5-m-thick concrete lid 25–30 m. The radioactive cloud from the explosion reached approximately 1 km. Due to calm wind conditions, approximately 90% of the materials deposited locally, while 100 PBq was dispersed away from the plant in an oblong fallout pattern approximately 300 km in length, including parts of Chelyabinsk, Sverdlovsk, and Tyumen counties. Almost all of the radioactive fallout occurred within the first 11 h.

(A 18) The major contaminants released were ^{144}Ce, ^{95}Zr, ^{95}Nb, and ^{90}Sr. Most fission products deposited on the ground, allowing the strontium isotopes to enter the food chain. A ban on food containing ^{90}Sr at concentrations greater than 2.4 Bq/g resulted in the destruction of 10,000 tons of agricultural produce in the first 2 years. All stores in Kamensk-Uralskiy which sold milk, meat, and other foodstuffs were closed as a precaution against consuming radioactive material, and new supplies were brought in 2 days later by train and truck.

(A 19) Approximately 10,000 people were evacuated from the high contamination area, while approximately 260,000 people remained in less contaminated areas. There were 1154 people in areas with a ^{90}Sr deposition density greater than 40 MBq/m^2, 1500 in areas with a deposition greater than 4 MBq/m^2, and 100,000 in areas with a deposition greater than 70 kBq/m^2. The highest individual doses were experienced by those evacuated within a few days of the accident. These people received an average external dose of 170 mSv and an average internal (gastrointestinal) dose of 1500 mSv; the average effective dose equivalent was approximately 520 mSv. The collective effective dose received by the evacuated people amounted to approximately 1300 man Sv.

(A 20) In the case of those that were not evacuated, the average 30-year committed effective dose for a group of approximately 10,000 people living in areas with a ^{90}Sr surface contamination level of 40–70 kBq/m^2 was estimated to be 20 mSv, and 4 mSv for a group of approximately 2000 people living in areas with a deposition density of 4–40 kBq/m^2. The collective effective dose received by the non-evacuated population (approximately 260,000 people) has been assessed as 1200 man Sv over a 30-year period, with figures pointing to 5000 man Sv.

(A 21) In the 1990s, the criteria for radiation protection of the population in the contaminated areas of Russia were revised. Protective measures were supposed to be undertaken in the areas with a dose level above 1 mSv/year.

A.5. Palomares

(A 22) The Palomares accident occurred on 17 January 1966 when two US military planes, a B-52 bomber and a KC-135 tanker aircraft, collided in the process of a midair refuelling operation above the town of Palomares, in the south-east of Spain on the Mediterranean coast. Both aircrafts were destroyed in the air. Four thermonuclear weapons, 11 men (four survived), and hundreds of tons of debris fell to earth in and around the town. Parts of the aircraft were scattered over a wide area. Two weapons landed without incident, one in a dry river bed near the mouth of the Almanzora river and the other in the sea, and both were recovered undamaged. The parachutes of the other two weapons failed to deploy; one fell in low mountains west of the town, and the other on agricultural lands to the east. The high explosives in these last two weapons detonated and burned, causing some of the plutonium inside to also burn and to be spread throughout the area. ^{239,240}Pu particulate contamination was distributed in varying degrees over a 2.26-km^2 area, including the northern edge of the village, farmlands, and non-cultivated terrains.

(A 23) This resulted in a 3-month response effort to identify, characterise, remove, and remediate the accident site. With a peak of approximately 680 personnel on 31 January 1966, the clean-up operation involved approximately 1600 individuals, the majority of whom were active duty US Air Force personnel (US Air Force Medical Services, 2001). Wherever the deposition density of alpha emitters was greater than 1.2 MBq/m^2, the contaminated vegetation and a surface layer of soil, approximately 10 cm depth, were collected, separated, and disposed of as radioactive wastes. The removed soil was replaced by fertile earth from uncontaminated areas. Arable land with levels below 1.2 MBq/m^2 was irrigated, ploughed to a depth of 30 cm, harrowed, and mixed. On rocky hillsides where ploughing was not possible, soil with a plutonium level greater than 0.12 MBq/m^2 was removed to some extent with hand tools. Bushes and trees with contamination levels above 3.7×10^{-2} Bq/m^2 were removed or pressure washed. Contaminated roofs and walls of houses were pressure washed until complete clean-up. In cases where complete decontamination was not possible, removal by mechanical procedures was carried out. The final amount of wastes produced from removed soil of approximately 1000 m^3 were placed in approximately 5000 metallic drums of 200 L each and sent to Savannah River Plant in the USA. Approximately 310 m^3 of vegetation wastes with levels above 7 kBq/m^2 were buried in a disposal trench; the other vegetation removed was burned and the ashes mixed and placed in drums with the most contaminated soil (Gutiérrez et al., 1994).

(A 24) Immediately after the decontamination operation, a radiological surveillance programme was established by the former Nuclear Energy Board and then continued indefinitely by the national research centre CIEMAT. Reports are presented periodically to the national regulatory body, the Nuclear Safety Council and the Spanish Council of Nuclear Safety (CSN). The radiological surveillance programme has included medical examinations and urine analyses to determine bioelimination of plutonium and americium for approximately 150 people per year. In the environment, sampling and analysis of soil, water, vegetation, crops, and livestock products, as well as marine water and sediments, have been performed since the accident.

(A 25) The medical controls for the population (total of 1043 people) have not shown any radiation-related findings. Of the urine analyses of local inhabitants undertaken since 1966, only 3.3% (153/628) have had a positive result. The percentage of people who have had their committed effective dose calculated is 5.5% (59/1066), with values that do not imply any significant radiological risk, as reported to CSN.

(A 26) The average annual concentration of plutonium in the air at Palomares (39 $\mu Bq/m^3$ in the rural area and 4 $\mu Bq/m^3$ in the urban area) since the accident implies an annual average dose to the population by inhalation that is 'significantly lower' than 1 mSv. The dose by ingestion of locally produced food, based on a large number of analyses and measurements of representative agricultural products, would also be much lower than 1 mSv/year (only 1% of the samples have shown contamination above 1 Bq/kg in the edible part of the food).

(A 27) In recent years, the socio-economic situation of the Palomares area has changed drastically, with continuous and growing economic development that involves high technical agricultural practices (with many greenhouses), intensive and extensive use of land, and a strong and stable development of tourism with a significant increase in new building. These changes in land use, involving the movement of large amounts of soil, could lead to higher availability of the remnant radioactive contamination, and therefore motivated the implementation of a programme for the adequate management of the most affected zones. In July 2000, CIEMAT communicated to the CSN that, in the so-called 'zone 2', the plutonium inventory within the top 45-cm layer of soil was 2.85 TBq. In 2003, the CSN established specific criteria for the use of soil in Palomares, which were ratified in 2007. The criteria refer to the top 15-cm layer of soil. Unrestricted use of soil is allowed if the assessed residual doses are lower than 1 mSv/year; partial restriction in land use and additional characterisation is necessary when the assessed residual doses are of the order of 1 mSv/year. Finally, a complete interdiction on the use of soil is adopted when the assessed residual doses could be above 5 mSv/year. Based on these criteria, the Government determined an occupation of the affected areas as the most appropriate way to proceed with an in-depth study of the situation that could lead to a definitive solution to the problem.

(A 28) A research plan on radiological surveillance of the area was approved with the objective of performing a detailed characterisation of the remnant contamination. Surface ^{241}Am contamination has been measured in the top 15-cm layer of soil in an area of 660 hectares (6.6 km^2), resulting in more than 63,000 records. Beyond the previously known existence of residual contamination in 20 Ha in the proximity of the impact points of the two weapons, this characterisation showed significant residual contamination levels in approximately another 20 Ha out of the 'zero contamination line' initially marked after the accident. This has justified the occupation of 40 Ha of terrain by the Public Administration. Once closed to the public, the most affected 40 Ha have been characterised with more than 255,000 records of surface ^{241}Am contamination in the upper 15-cm layer of soil. Static measurements of 'in-situ' gamma spectrometry and external dose levels have been performed in 581 points, from which 1698 unaltered samples of soil have been taken and analysed. Also, boreholes have been created in 310 places (280 up to a depth between 2 and 5 m; 30 between 0.5 and 1 m) in order to evaluate the deeper migration of the residual contamination. This detailed information will allow elaboration of the recommendations leading to the final rehabilitation of the affected terrains (Barrigós, 2008).

(A 29) Close interaction and fluid communication has been maintained with the affected communities, including frequent meetings with regional and local authorities, as well as with other stakeholders such as individual citizens, environmental organisations, local media, etc. (Barrigós, 2008). This has contributed to generate and maintain confidence in the experts' assessments and the authorities' recommendations.

A.6. Chernobyl/Commonwealth of Independent States countries

(A 30) The Chernobyl accident that occurred in April 1986 resulted in widespread contamination of inhabited areas in the republics of Belarus, Russia, and Ukraine of the former Soviet Union. Immediately after the accident, the inhabitants of the city of Prypiat close to the power plant were evacuated, followed by the entire population living in settlements located within a 30-km radius around the plant. Restrictions on access and consumption of foodstuffs were also adopted rapidly, as well as decontamination, hydrological, and agricultural countermeasures to minimise the impact of the contamination. During the months following the emergency phase, concern increased progressively regarding whether or not further relocation of populations and supplementary countermeasures were needed. The long-term rehabilitation issue emerged progressively during the late 1980s when it became more and more evident that the protection strategies adopted after the emergency phase, basically aiming at moving the inhabitants away from the most contaminated areas and reducing and controlling the contamination in the environment whenever possible, were insufficient to durably protect the population still residing in large, less-contaminated areas.

(A 31) The long-term contamination in these areas was a permanent worry for the population as far as health was concerned because of the remaining uncertainty concerning protracted exposure, particularly due to internal contamination. It was also a very serious handicap for the long-term preservation of the quality of life of the inhabitants and the sustainable maintenance of the socio-economic infrastructure. This led the Governments of Belarus, Russia, and Ukraine to elaborate and adopt ambitious national laws in the early 1990s in an attempt to organise radiation monitoring and health surveillance, and to improve the social and economic living conditions of the population residing in the contaminated areas. The objective of these laws was mainly to address long-term issues through a series of national countermeasures and compensation mechanisms, designed mainly according to radiological protection criteria.

(A 32) In Belarus, for instance, two laws were published to define the principles governing the social protection of the affected population and the status of contaminated areas. The first law, voted in February 1991, concerned 'the social protection of citizens affected by the disaster at the nuclear power plant of Chernobyl' and clarified the status of those affected by the accident: liquidators, populations, and workers in the contaminated areas, as well as the compensation allocated in each case. The second law, voted in November 1991, which concerned 'the legal status of the contaminated areas following the disaster at the nuclear power plant of Chernobyl' defined the conditions and means for organising the social and economic activities in the areas, as well as the scientific accompanying programme. It also stipulated the zoning organisation of the Belarus regions (Table A.1). Both laws applied to approximately 2 million Belarusian people and recognised that 20% of the Belarusian territory (approximately 40,000 km^2) were significantly contaminated.

(A 33) Schematically, the rehabilitation programmes adopted in the early 1990s relied on further restriction of human presence in the contaminated areas (mandatory or voluntary relocation), and on strictly controlling the level of contamination in foodstuffs and the whole-body contamination of individuals. Many countermeasures were focused on the control and improvement of the radiological quality of agricultural products in collective farms; private production was restricted as much as possible because of difficulty in controlling and monitoring its quality.

(A 34) In 2001, the law on 'the social protection of citizens affected by the disaster at the nuclear power plant of Chernobyl' was amended and clarified. It was then established that in areas where conditions of life and work are not subject to any restriction, the average total exposure (external and internal) of the population should not exceed 1 mSv/year (excluding background). This law stipulated that:

- if the average exposure of the population is more than 1 mSv/year, protective measures must be implemented;
- if the average exposure of the population is between 0.1 and 1 mSv/year, actions to reduce exposures should not be deleted but adapted to the situation; and
- if the average exposure of the population is less than 0.1 mSv/year, protective measures are not necessary.

Table A.1. Zoning criteria adopted in Belarus in 1991.

Zoning criteria	Official designation of zones
$37 < {}^{137}Cs < 185$ kBq/m^2 Individual dose < 1 mSv/year	Periodic radiation monitoring
$185 < {}^{137}Cs < 555$ kBq/m^2 $18.5 < {}^{90}Sr < 74$ kBq/m^2 $0.37 < Pu < 1.85$ kBq/m^2 Individual dose > 1 mSv/year	Zone with resettlement rights
$555 < {}^{137}Cs < 1480$ kBq/m^2 $74 < {}^{90}Sr < 111$ kBq/m^2 $1.85 < Pu < 3.7$ kBq/m^2 Individual dose < 5 mSv/year	Zone of secondary resettlement
${}^{137}Cs > 1480$ kBq/m^2 ${}^{90}Sr > 111$ kBq/m^2 $Pu > 3.7$ kBq/m^2 Individual dose > 5 mSv/year	Zone of priority resettlement
Zone of evacuation (exclusion zone)	

(A 35) As far as the control of foodstuffs is concerned, authorities have adopted a pragmatic approach by reducing the concentration criteria as the situation improved. Table A.2 illustrates the evolution of food contamination criteria from 1986 to 1999 in Belarus.

(A 36) It should be noted that, with minor changes, this legal framework remained the basis of the successive rehabilitation programmes that were implemented until the late 2000s, i.e more than 20 years after the accident.

(A 37) Despite the huge amount of national resources dedicated to the rehabilitation programmes in the early 1990s, the protection strategies failed to properly consider the complexity of the situation created by the contamination. In particular, they did not succeed in mobilising the local communities and the individuals who felt progressively powerless in the face of the radiological situation. This situation contributed to generate a general feeling of loss of control of daily life, exclusion, and abandonment among the inhabitants.

(A 38) During the mid 1990s, the continuous degradation of the economic situation due to both the collapse of the Soviet Union and the financial burden of the rehabilitation programmes pushed the inhabitants of the areas to restart private production and to rely ever more on wild products to ensure their daily subsistence. In the absence of individual knowledge and adequate means to control the radiological quality of foodstuffs at the local level, the effect of this change was inevitably a significant increase in the level of exposure within the population, and particularly among children because of the importance of dairy products in their diet. This put strong pressure on the authorities and experts, and contributed to aggravate further the loss of confidence of the population in their ability to manage the situation.

(A 39) Faced with this difficult situation, the authorities tested new approaches, such as the ETHOS Project in the late 1990s and the CORE Programme in the early 2000s in Belarus, with the aim of involving the population directly in the management of the radiological situation. These new approaches demonstrated that the

Table A.2. Evolution of ^{137}Cs contamination limits in foodstuffs in Belarus from 1986 to 1999.

Years	^{137}Cs contamination (Bq/kg, Bq/L)			
	1986	1993	1996	1999
Foodstuffs				
Drinkable water	370	18.5	18.5	10
Milk	370	111	111	100
Butter	7400	-	185	100
Meat:				
Beef	3700	600	600	500
Lamb	3700	-	600	500
Pork, poultry	3700	370	370	180
Potatoes	3700	370	100	80
Fruits	-	-	100	40
Wild berries	-	185	185	185
Fresh mushrooms	-	-	370	370
Dried mushrooms	-	3700	3700	2500
Baby food	-	-	-	37

direct involvement of local stakeholders in the day-to-day management of a radiological situation is feasible, and evidenced the potential for implementing many protective actions in day-to-day life in addition to the collective actions taken by the authorities. These approaches also demonstrated that to be sustainable, management of a radiological situation by stakeholders must rely on a dynamic of economic development relying primarily on individual initiatives of the local actors in partnership with national and international institutions and organisations.

A.7. Chernobyl/Norway

(A 40) The Chernobyl fallout in Norway was significant and had serious agricultural consequences (Brynildsen et al., 1996; Tveten et al., 1998). As the geographical extent and the potential long-term consequences of the fallout emerged during the summer of 1986, the Government passed a resolution regarding compensation for all farmers and other producers for economic losses due to the mitigating actions. The most affected areas in Norway are rural. Breeding of cattle, sheep, goats, and reindeer is common in these areas, and summer grazing on rough forest and mountain pastures is part of traditional agricultural practices. High uptake of radiocaesium in plants growing in these poor soils has contributed to a persistent contamination problem in animal production. Twenty-two years after the accident, countermeasures are still needed in large areas of sheep and reindeer production, as well as smaller areas of dairy cow and goat production, for compliance with food intervention levels. The countermeasures are expected to be needed for at least another decade (e.g. Skuterud et al., 2005a).

(A 41) The Norwegian radiological protection criteria in the Chernobyl management was based on the recommendations of the ICRP concerning exposures of the public, with 5 mSv as the maximum dose during the first year after the accident, and 1 mSv/year in subsequent years. A range of measures were needed to comply with these criteria, including dietary advice to consumers of reindeer meat and freshwater fish (Strand et al., 1992). The measures reduced the average ingestion doses of reindeer herders approximately 10-fold. However, without measures, there is continued potential for doses exceeding 1 mSv/year among reindeer herders in central Norway (Skuterud et al., 2005b).

(A 42) The Chernobyl fallout management in Norway focused on maintaining domestic food production and consumer confidence in these products. Control of contamination levels in traded foods was applied, and intervention limits for radiocaesium were established (600 Bq/kg in basic foodstuffs). However, to avoid condemnation of 85% of the total national reindeer production, and to maintain a meaningful business base for reindeer herders (as well as Sami culture and lifestyle), the intervention limit for radiocaesium in reindeer meat was increased in the autumn of 1986 to 6000 Bq/kg (from 1987, this was also applicable to wild freshwater fish and game). This was justified by the low average consumption of these products by the general Norwegian population. As the situation improved, the intervention limit for reindeer meat was reduced to 3000 Bq/kg in 1994.

(A 43) During 1986, approximately 2850 tons of meat, worth nearly 18 million USD, was condemned. In recognition of the long-term perspective of the contamination problems, the authorities realised that measures were needed to reduce the high cost associated with monitoring and compensation for condemned meat and milk. In addition, condemnation produced waste. The procedures developed for monitoring live animals (sheep, cattle, and reindeer; Brynildsen and Strand, 1994) have been particularly appreciated, both by animal owners and the authorities, since they rapidly determine if animals can be slaughtered or should be given clean feed before slaughter (with compensation for extra labour, fodder, construction of enclosures, etc.). Caesium binders mixed in concentrates, added to salt licks, or applied as rumen boli have also been popular measures with no extra economic costs for the producers. Early slaughtering was applied as a measure in reindeer herding, with associated compensation for reduced weight of animals. Many of the measures were developed and tested in the field, with the involvement of local people, and this approach has been regarded as important for the success of the strategies adopted.

(A 44) Elevated contamination levels in wild products, combined with significant consumption of these products by the rural population, particularly reindeer herders, led to a need for advice on the level of consumption of various products and how to cook in order to reduce radiocaesium intake. In addition, the authorities monitored radiocaesium levels in reindeer herders for surveillance of doses to the most exposed population group. Maybe even more importantly, this monitoring made the contamination situation more tangible and controllable for the people (Mehli et al., 2000). More than 20 years after the accident, there is a continued request for this monitoring from the reindeer herders, motivated by their willingness to maintain control of the radiological situation but also because of the still open discussions on risks associated with long-term, low-dose exposure to radiation.

(A 45) To manage the extensive monitoring of various animals and products in rural areas, the authorities equipped nearly 60 local food control laboratories and veterinarians with detectors for radiocaesium measurement in 1986–1987 (Strand et al., 1987). These also freely served the people if they wanted to check contamination levels in their own products. This monitoring network helped to build significant local knowledge on contamination levels.

(A 46) It has been estimated that the various countermeasures in animal production during the first 10 years, costing some 70 million USD in total, reduced the condemnation of meat worth nearly 300 million USD (Tveten et al., 1998). Additionally, monitoring and controlling animals and foodstuffs probably contributes to maintaining the public's confidence in Norwegian products, thereby avoiding even more dramatic economic consequences associated with market drops.

(A 47) The focus on local competence and direct involvement of the affected population in countermeasure application and monitoring in Norway was a result of both the request from the population in the contaminated areas, and the recognition by the central authorities that the local food producers had detailed knowledge of importance for everyday management of the contamination problem. This local focus appears to be another success of the Chernobyl fallout management in Norway.

A.8. Chernobyl/UK

(A 48) Radiocaesium originating from the accident at the Chernobyl nuclear power plant in the Ukraine was deposited across the UK on 2–4 May 1986. The highest levels of radiocaesium deposition, in the range of 20–40 kBq/m^2, occurred in the uplands of western Britain, where sheep farming is an important agricultural activity. A countrywide programme of sampling carried out after the accident identified sheep meat as the foodstuff of most concern. To protect consumers, a maximum limit of 1000 Bq/kg radiocaesium was applied to sheep meat affected by the accident. This limit was introduced in the UK in 1986, based on advice from the European Commission's Article 31. Under powers provided in the Food and Environment Protection Act 1985 (FEPA), emergency orders have been used since 1986 to impose restrictions on the movement and sale of sheep exceeding the limit in certain parts of Cumbria, North Wales, Scotland, and Northern Ireland. The orders define geographical areas, often termed 'restricted areas', within which the controls must be followed. Under the FEPA orders, sheep with levels of contamination above the limit are not allowed to enter the food chain. Due to the particular chemical and physical properties of the peaty soil types present in the upland areas of the UK, the radiocaesium is still able to pass easily from soil to grass and hence accumulate in sheep. Consequently, more than 20 years after the accident, areas exist where restrictions are still in place. Initially, these restricted areas were large, but they have reduced substantially as levels of radioactivity have fallen, with all restrictions lifted in Northern Ireland in 2000. Table A.3 gives a breakdown of the number of sheep and farms under restrictions for 1986, 1990, 2000, and 2007. The restrictions, which were implemented as a response to an emergency exposure situation, have become part of a protection strategy for what is now considered as an existing exposure situation.

(A 49) It was not possible to implement protective measures to reduce levels of radiocaesium in vegetation in the restricted areas due to the physical limitations of the terrain and the environmentally sensitive nature of these areas. Nevertheless, the development of a very well-designed monitoring programme following the Chernobyl accident did enable lamb production to be sustained and the livelihoods of sheep farmers to be protected. Furthermore, consumer confidence in lamb was maintained. The monitoring programme, known as the 'Mark and Release' scheme, has operated in the restricted areas since 1986. Under this scheme, a farmer wishing to move sheep out of a restricted area can have the animals monitored to determine their level of radiocaesium. A live monitoring technique is used which, to allow

Table A.3. Number of sheep and farms under restrictions in the UK for 1986, 1990, 2000, and 2007.

	Farms	Sheep
June 1986	8914	4,225,000
August 1990	757	647,000
May 2000	387	231,500
February 2007	369	196,500

for inherent variability in live monitoring results, applies a working action level of 645 Bq/kg (rather than 1000 Bq/kg). Any sheep which exceed the working action level are marked with a dye and are not released from restrictions. Those which pass are allowed to enter the food chain.

(A 50) Since 1986, sheep farmers in the restricted areas started to become aware that their lambs could pass the 'Mark and Release' test if they were brought down from the upland unimproved pastures to improved lowland pasture for a period of fattening prior to slaughter. Subsequently, these sheep farmers have adapted their husbandry practices to make use of their own improved land or rented land to fatten their lambs prior to slaughter. Live monitoring has become part of this routine and is generally accepted by farming communities as the new practice. The restrictions will remain in place for several years to come.

A.9. Goiânia, Brazil

(A 51) On 13 September 1987, two scavengers found an abandoned teletherapy device in a derelict medical clinic in Goiânia, Brazil. The machine contained a radioactive ^{137}Cs source with an activity of 50.9 TBq in the form of powdered and soluble $^{137}CsCl$. After removing the rotating assembly of the machine containing the source from its shield, they took it home and managed to rupture it and spread pieces about the property. Both became ill within hours. Five days later, they sold the pieces of the rotating assembly to a junk dealer in the neighbourhood. This dealer noticed a luminescence emanating from the unit and used tools to cut the unit apart to gain access to the material inside. The rupture allowed the $^{137}CsCl$ powder to disperse easily and be further distributed. Several land areas and 129 people were significantly contaminated, resulting in four deaths and one forearm amputation.

(A 52) ^{137}Cs contamination was spread by social contacts, the sale of contaminated material, the movement of pieces of the source, and wind and rain dispersal. Contamination was found on seven major properties; in 42 residences, including 22 homes of family and friends who were evacuated, and 20 others where radiation levels ranged from 1 to 10 mSv/h; and on 68 of more than 10 million bank notes tested. The population was internally exposed by inhalation and the ingestion of fruits and vegetables, and externally exposed to the penetrating ^{137}Cs gamma radiation, but the drinking water supply was found to be clean. More than 4000 urine and faecal samples from a total of 80 people were analysed between October 1987 and January 1988. The estimated collective doses were 56.3 man Sv from external exposures and 3.7 man Sv from internal exposures, including 14.9 man Sv (external) and 2.3 man Sv (internal) for the four people who died.

(A 53) More than 550 decontamination workers were mobilised. Contaminated materials in the environment were removed from the various sites and loaded into containers, with liquids being immobilised in concrete. Decontamination limits for solids were set by the national standard. Anything contaminated below 74 kBq/kg was considered to be clean and unaffected by the accident. The contamination level was characterised by the contact radiation level, with values of 2 and 20 mSv/h being the respective limits for low- and medium-level contamination. An estimated activity of 44 TBq of ^{137}Cs (of the 50.9 TBq of the source) was recaptured during the decontamination effort, which left the area with no significant residual hazard. The total volume of waste generated was 3500 m^3.

(A 54) The initial media coverage of the accident raised a lot of concern for a community with recent memories of the Chernobyl reactor accident in the former Soviet Union. The situation improved when the news media focused their efforts on reporting the actions implemented and public education. However, beyond the direct cost in human lives and medical treatment and care of victims, monitoring of people and the contaminated area, and the countermeasures described above, the economic and social consequences of the accident were very significant. Even without any agricultural contamination, the wholesale value of the entire state's agricultural production fell by 50% within 2 weeks of the announcement of the accident. Manufactured goods from Goiânia state experienced a drop of 40% in their sale prices for approximately 30–45 days. There was a very definite impact on the number of homes sold, home sale prices, rental prices, and land prices, and this was more acute nearer to the contaminated areas. The negative impact on hotel reservations and tourism was approximately 40%, even in areas more than 1 hour's drive away. Some residents of Goiânia were not allowed to register in hotels, to fly on aeroplanes, or to travel on buses. Official certificates of non-contamination were requested for people and goods everywhere.

(A 55) In the long term, due to heavy rains, the material was easily transported through the streets in addition to in-depth soil migration. Therefore, an additional decontamination was necessary for long-term recovery, mainly dealing with contaminated houses, gardens, and streets. At the time, Brazilian regulations did not cover remediation, and the only number that people understood and accepted was the dose limits for practices. Therefore, it was decided to use an approach which leads to 5 mSv for the first year but an average of 1 mSv/year considering the weathering and physical decay of caesium over 70 years. As a conceptual model, it considered indoor and outdoor external exposures in addition to inhalation of resuspended material and ingestion of food available from private gardens (such as vegetables, chicken, eggs, fruits). The criteria adopted for external exposure was 1 mSv for indoors and 3 mSv for outdoors, and the criteria for internal doses was 1 mSv/year. The authorities had to use a similar approach to that established in the national regulation for practices.

(A 56) Follow-up of all recovered areas has been performed over the years. However, in 1996, the environmental monitoring programme was stopped because of public stress, which caused behaviours such as TLDs disappearing from monitored houses, people not allowing workers to go into monitored places, etc. A new survey was requested in 2004 by the District Attorney in which some 'hot spots' of contamination, with levels higher than the operational level, were found on the streets and were removed in spite of not being of primary concern considering their location. The worst-case dose scenario indicated an effective dose of 3.2 mSv/year.

(A 57) A lesson learnt from the Goiânia accident is that the post-accident phase also requires planning and co-ordination with different stakeholders, particularly with the local population. Many resources were used to implement actions that could have been avoided with better planning of management of the situation, and better awareness of all involved entities on how to deal with this type of situation.

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ICRP Publication 111

Annals of the ICRP

Erratum

Erratum to the References in Publication 98, (Volume 35, Issue 3)

The Publisher would like to point out that the last page of the references were omitted from the PDF and printed versions of the above publication. They are reproduced in full below:

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ICRP Publication 111

Corrigendum

Corrigendum to 'The History of ICRP and the Evolution of its Policies' [Ann. ICRP 39(1)]

R.H. Clarke, J. Valentin

The authors would like to point out that there were errors present in Table 1.3, on page 84, under 'Committee 1 Chair'.

The error as present is:

1985–2001	Warren K Sinclair, USA
2001–2009	Roger Cox, UK
2009–	Ohtshura Niwa, Japan

The corrected form is:

1985–1997	Warren K Sinclair, USA
1997–2005	Roger Cox, UK
2005–	Julian Preston, USA

The Publisher and Authors apologize for this error.

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