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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 at the 1928 International Congress of Radiology to advance for the public benefit the science of radiological protection. ICRP provides recommendations and guidance on protection against the risks associated with ionising radiation from artificial sources such as those widely used in medicine, general industry, and nuclear enterprises, and from naturally occurring sources. These are published approximately four times each year on behalf of ICRP as the journal *Annals of the ICRP*. Each issue provides in-depth coverage of a specific subject area.

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ICRP is an independent international network of specialists in various fields of radiological protection, typically numbering more than two hundred eminent scientists, policy makers, and practitioners from around the world. ICRP is composed of a Main Commission, a Scientific Secretariat, four standing Committees (on radiation effects, doses from radiation exposure, protection in medicine, and the application of ICRP recommendations), and generally about twenty Task Groups.

The Main Commission consists of a Chair and twelve other members. Committees typically comprise just over 15 members each. Task Groups are usually chaired by an ICRP Committee member and usually contain a number of specialists from beyond the Main Commission and Committees. They are assigned the responsibility for drafting reports on various subjects, which are reviewed and finally approved by the Main Commission. These reports are then published as *Annals of the ICRP*.

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ICRP PUBLICATION 146

Radiological Protection of People and the Environment in the Event of a Large Nuclear Accident

Update of ICRP *Publications 109* and *111*

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ICRP Publication 146

Editorial

BE PREPARED

Accidents happen. Aircraft crash, ships sink, trains derail, chemical factories explode, dams break, and nuclear power plants fail. We also face natural disasters such as floods, droughts, hurricanes and typhoons, earthquakes, heat waves, volcanic eruptions, tornados, meteor strikes, forest fires, ice storms, mud slides, and tsunami. Each of these can shake a city, region, or nation. A few have shaken the world. The consequences can be political, societal, environmental, economic, and, most of all, human.

At the heart of accidents and disasters are personal consequences. The most obvious of these are physical injury and death, sometimes on a massive scale. On 3 December 1984, a leak from a pesticide factory in Bhopal, India killed at least 3000 people and more than 100,000 suffered permanent disability. Compensation for injury was awarded to more than half a million people (Broughton, 2005).

These figures are staggering, but looking more deeply reveals that the consequences of accidents and disasters go far beyond the obvious. A flood can destroy a village, washing away homes that have stood for generations and destroying culturally significant places, breaking a community's connection with its own history. Releases from facilities can taint entire regions whether there are immediate health consequences or not. Even if people can continue to live there, property values drop, populations dwindle, and job opportunities disappear as new people and businesses are reluctant to move in. Looking even more closely, consider the despair of grandparents whose grandchildren will no longer visit them in their homes, or families that break apart because of conflicting priorities.

Learning to deal with accidents and natural disasters is essential to reduce human suffering and environmental impacts.

Everyone hopes that there will never be another nuclear accident on the scale of what occurred in 2011 at the Fukushima Daiichi nuclear power plant in Japan, or, even worse, in 1986 at the Chernobyl nuclear power plant in the USSR (now Ukraine). Today, there are approximately 440 nuclear power reactors supplying electricity globally, and approximately 15 more are under construction (WNA, 2020).

ICRP has no position on nuclear power beyond the ethical principles and fundamental recommendations that apply universally. Ethically, this means that good must be preferred over harm, actions must be well informed and carefully considered, and people must be treated fairly and with dignity. We call these the four core ethical values of beneficence/non-maleficence, prudence, justice, and dignity (ICRP, 2018). To enact these, we use the three principles of radiological protection: justification, optimisation of protection, and individual dose limitation. Respectively, these ensure that good outweighs harm, that protection is the best for the circumstances, and that an unfair dose is not imposed on any individual. In short, ICRP's aim in all circumstances is to ensure that, where ionising radiation is involved, people and the environment are protected.

Given this, ICRP applauds all efforts to improve nuclear safety (e.g. NEA, 2016). Our mission is to promote radiological protection. Avoiding and mitigating nuclear accidents, especially those that release radioactive material, are part of protecting people and the environment from detrimental exposures to radiation.

Nonetheless, we must be prepared for another accident. This is an important part of our work, related not only to nuclear power but also, for example, the use of radiation in medicine [see, for example, *Publication 112* 'Preventing Accidental Exposures from New External Beam Radiation Therapy Technologies' (ICRP, 2009a)].

The present publication updates and replaces two previous publications, coincidentally released in the same year as *Publication 112*, and less than 2 years before the Fukushima Daiichi accident:

- *Publication 109* 'Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations' (ICRP, 2009b); and
- *Publication 111* 'Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas' (ICRP, 2009c).

In theory, the scope of the present publication is narrower than that of *Publications 109* and *111*, as it applies specifically to large nuclear accidents. In practice, these previous publications focused largely on these types of accidents, although the general principles are the same for accidents of almost any scale. Even so, additional recommendations on radiological protection for other types of accidents are being considered.

One of the advantages of combining the two previous publications into one is that the response can be considered more holistically, and more attention can be paid to the transition from the early and intermediate phases to the long-term phase of the accident. The current publication makes it easier to follow the thread through the emergency response to the recovery process, and importantly includes advice on preparation for the long-term phase.

As one might expect, the present publication draws heavily on nearly 10 years of experience following the Fukushima Daiichi accident. However, even after nearly 35 years, there are new insights from the Chernobyl accident too. For example, it is now clearer to see the social impacts of the Chernobyl accident in light of the Fukushima Daiichi accident, and the Fukushima Daiichi accident has taught us that there can be enormous impacts even without immediate and widespread catastrophic health impacts. Reporting on the Fukushima Daiichi accident, the United Nations Scientific Committee on the Effects of Atomic Radiation noted that 'no radiation-related deaths or acute diseases have been observed among the workers and general public exposed to radiation from the accident' and 'no discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants'; however 'the most important health effect is on mental and social well-being' (UNSCEAR, 2013).

This publication could not have been developed in a vacuum. Over nearly a decade, ICRP embarked on what was perhaps its most extensive work stream since the development of our last fundamental recommendations (ICRP, 2007). The ICRP Main Commission met with delegates from Japan in April 2011, just weeks after the Fukushima Daiichi accident. Soon thereafter, ICRP established Task Group 84 on Initial Lessons Learned from the NPP Accident in Japan vis-à-vis the ICRP System of Radiological Protection. The next year, a summary of the task group findings (ICRP, 2012) was accepted by the Main Commission at their meeting in Fukushima City, and not long after, members of Task Group 84 published a paper with considerably more detail (González et al., 2013).

This initial assessment would influence ICRP's programme of work for many years. Notably, this included establishing Task Group 93 on Update of ICRP *Publications 109* and *111*: the group that developed the present publication.

In parallel, ICRP had begun a series of dialogue meetings in Fukushima, the first of which was held in November 2011. The purposes were: to create a forum for free and open discussion of challenges in the recovery process; to share experiences among experts and citizens of Japan and countries directly impacted by the Chernobyl accident, such as Belarus and Norway; to learn about the situation directly from those involved to ensure that any new ICRP recommendations would be as relevant and useful as possible; and, of course, to help people who were facing a very difficult situation (Kotoba, 2015). What became known as the 'Dialogue Initiative' proved to be highly successful on all counts. As of 2020, a total of 22 dialogue meetings have been held, initially led by ICRP but now fully in the hands of local people (Lochard et al., 2019).

The Dialogue Initiative was invaluable in developing the current publication. Not only did the close interactions with people on the front lines provide a deeper level of understanding, but several local participants also participated in drafting and review of the present publication.

Throughout the process, ICRP was also in frequent contact with many experts, health professionals, affected residents, and authorities including Japanese government and expert organisations and nuclear power plant operators, to ensure that all aspects of radiological protection after a large nuclear accident were addressed.

A number of international organisations were involved in the development of the publication. This was through many relatively informal interactions during drafting, and through a more formal peer review later in the process.

All ICRP publications now undergo public consultation before they are completed. This crucial step gives anyone the opportunity to comment on our work via a web-based portal, and is important to make sure we have heard and considered all view-points. Given the nature of this publication, and the significant interest expressed by many people, for the first time ever, comments were accepted in English and Japanese, and the comment period was extended. Another first was a public meeting held in Japan during the consultation, so people could hear how we were responding to early comments, and have an opportunity to express their views in person. In all, more than 300 sets of comments were received, approximately 10 times more than for most ICRP publications, and second only to the number of comments received on the current set of fundamental recommendations (ICRP, 2007). I am convinced that this level of interest has increased the quality of this publication, and am thankful that so many people took the time to share their views.

Finally, on a more personal note, I would like to acknowledge the kindness of the many people from and in Japan who I have had the pleasure of meeting since 2011, and the European friends and colleagues who have shared their experiences related to the Chernobyl accident. On many occasions, I have been humbled by their perseverance, ingenuity, and generosity of spirit. I am saddened that the accidents happened, and know that people are still suffering, but one silver lining is the friendships that have grown between people that would not otherwise have met. I hope another silver lining is a more robust understanding of the consequences of nuclear accidents and improved preparedness for the future.

Christopher H. Clement
Editor-in-Chief

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ICRP Publication 146

RADIOLOGICAL PROTECTION OF PEOPLE AND THE ENVIRONMENT IN THE EVENT OF A LARGE NUCLEAR ACCIDENT: UPDATE OF ICRP *PUBLICATIONS 109* AND *111*

ICRP PUBLICATION 146

Approved by the Commission in July 2020

Abstract–This publication provides a framework for the protection of people and the environment in a large nuclear accident, drawing on experience of the Chernobyl and Fukushima accidents. In managing accidents, the Commission makes a distinction between the early and intermediate phases, considered emergency exposure situations, and the long-term phase, considered an existing exposure situation. In emergency and existing exposure situations, mitigating the radiological consequences on humans and the environment is achieved using the fundamental principles of justification of decisions and optimisation of protection. The Commission recommends a set of reference levels for the optimisation of protection of the general population and responders, both on-site and off-site, for all accident phases. Implementation of protective actions should not only take account of radiological factors, but also consider societal, environmental, and economic aspects to protect health, ensure sustainable living conditions for the affected people, ensure suitable working conditions for the responders, and maintain the quality of the environment. In the early phase of an accident, urgent protective actions have to be taken, often with little information. Decisions rely on actions identified during preparedness planning that best match the actual situation. During the intermediate phase, protective actions reduce radiation exposures progressively. When the radiological situation is sufficiently characterised, the long-term phase begins, during which further protective actions are implemented to improve living and working conditions. Authorities should invite key representative stakeholders to participate in the preparedness process, and in the management of the successive phases of the accident. It is the role of the authorities to implement radiation monitoring and health surveillance, and to provide the conditions and means for sharing information and expertise to enable individuals to develop a radiological protection culture and to make informed decisions about their own protection.

Keywords: Chernobyl accident; Fukushima accident; Emergency exposure situation; Existing exposure situation; Justification; Optimisation; Reference level; Protective actions; Stakeholder involvement; Co-expertise process; Radiological protection culture

MAIN POINTS

- **A large nuclear accident causes a breakdown in society affecting all aspects of individual and community life. It has large and long-lasting societal, environmental, and economic consequences.**

- **Characterisation of the radiological situation on-site and off-site is essential to guide protective actions, and should be conducted as quickly as possible.**

- **The Commission recommends using reference levels to guide the implementation of protective actions during the early, intermediate, and long-term phases of an accident.**

- **The objective of radiological protection is to mitigate radiological consequences for people and the environment whilst, at the same time, ensuring sustainable living conditions for the affected people, suitable working conditions for the responders, and maintaining the quality of the environment.**

- **Responders, who are likely to be the most exposed individuals, should be provided with appropriate protection, taking into account the requirements of the response on-site and off-site.**

- **Responsible organisations should promote the involvement of local communities in a co-operative process with experts (co-expertise process) to help achieve a better assessment of the local situation, the development of an adequate practical radiological protection culture, and informed decision-making among those affected.**

- **Preparedness planning is essential for mitigating the consequences during phases of a large nuclear accident, and should involve stakeholders.**

EXECUTIVE SUMMARY

(a) Large nuclear accidents result when there are significant releases of radioactive material into the environment, impacting widespread areas and affecting extensive populations. They are unexpected events that profoundly affect individuals, society, and the environment. They generate complex situations and legitimate concerns, particularly regarding health, for all those affected by the presence of undesirable sources of radioactivity. Management of these situations requires the long-term mobilisation of considerable human and financial resources. Radiological protection, although indispensable, only represents one dimension of the contributions that need to be mobilised to cope with the issues facing all affected individuals and organisations.

(b) For managing these events, the Commission makes a distinction between the early and intermediate phases of the accident, considered as emergency exposure situations, and the long-term phase, considered as an existing exposure situation. The Commission also distinguishes between on-site and off-site to differentiate activities at the damaged installation and in the affected areas. The present recommendations may be applicable to other types of radiological emergencies, with due consideration of the differences that inevitably exist between a nuclear accident and these emergencies.

(c) Characterisation of the radiological situation on-site and off-site is essential to guide protective actions, and should be conducted as quickly as possible to address the uncertainties regarding the intensity, duration, and extent of the radioactive contamination.

(d) In emergency and existing exposure situations, the objectives of radiological protection are achieved using the fundamental principles of justification and optimisation. The principle of justification ensures that decisions regarding the implementation of protective actions result in a benefit for the affected people and the environment, as these actions can potentially induce significant disruption. The principle of optimisation of protection applied with reference levels aims to limit inequity in the distribution of individual exposures, and to maintain or reduce all exposures to as low as reasonably achievable, taking into account societal, environmental, and economic factors.

(e) Justification and optimisation are applied in the mitigation of radiological consequences to people and the environment during all phases of the accident, and should take careful account of all non-radiological factors in order to preserve or restore the living and working conditions of all those affected, including decent lifestyles and livelihoods.

(f) People involved in the direct management of the consequences of a nuclear accident are diverse in terms of their background, status, degree of preparation, and training on radiological protection. They include emergency teams (firefighters, police officers, medical personnel, etc.), workers (occupationally exposed or not), and other people such as elected representatives or citizens acting as volunteers. All these categories are considered by the Commission as 'responders'.

They deserve to be adequately protected and provided with suitable working conditions.

(g) For the protection of responders on-site, the reference level during the early phase should not generally exceed 100 mSv, while recognising that higher levels, in the range of a few hundred millisieverts, may be permitted to responders in exceptional circumstances to save lives or to prevent further degradation at the facility leading to catastrophic conditions. Lower reference levels may be selected based on the situation, in accordance with the severity of the accident. During the intermediate phase, the reference level should not exceed 100 mSv. For the long-term phase, the reference level should not exceed 20 mSv per year, with possible special arrangements limited in time. The Commission recommends that responsible organisations should take all practical actions to avoid unnecessary accumulation of exposures for responders involved in both the early and intermediate phases.

(h) For the protection of responders off-site, the Commission recommends selection of a reference level not exceeding 100 mSv for the early phase and 20mSv per year for the intermediate phase. For the long-term phase, the reference level should be selected within the lower half of the recommended band of 1–20 mSv per year.

(i) For the protection of people, the reference level should not generally exceed 100 mSv for the entire duration of both the early and intermediate phases. The Commission recommends that responsible organisations should adopt a lower reference level whenever possible. For the long-term phase, the reference level should be selected in the lower half of the recommended band of 1–20 mSv per year for existing exposure situations, taking into account the actual distribution of doses in the population and the societal, environmental, and economic factors influencing the exposure situation. The objective of optimisation of protection is a progressive reduction in exposure to levels towards the lower end of the band, or below if possible.

(j) In some nuclear accident scenarios, release of radioactive iodine can result in high thyroid exposures due to inhalation or ingestion. Specific efforts should be made to avoid, or at least reduce, intakes of radioactive iodine, particularly in children and pregnant women. During the early phase or just after, exposed people should be monitored to detect potential exposure to radioactive iodine.

(k) Management of the protection of people in affected areas in the intermediate and long-term phases is a complex process involving not only radiological factors, but also societal, environmental, and economic considerations. This process includes actions implemented by national and local authorities, and self-help protective actions taken by residents of the affected areas. In these phases, radiation exposures of people living and working in affected areas are largely dependent upon individual lifestyles. The Commission recommends that authorities, experts, and stakeholders should co-operate in the so-called 'co-expertise process' to share experience and information, promote involvement in local communities, and develop a practical radiological protection culture to enable people to make informed decisions. Individual measurements with suitable devices, together with relevant information, are very helpful in the implementation of this process.

(l) For the protection of the environment, the Commission recommends that fauna and flora should be protected using its framework based on Reference Animals and Plants, together with derived consideration reference levels. The impacts of protective actions on pets and livestock, as well as on the environment, in terms of sustainable development, conservation, preservation, and maintenance of biological diversity should also be addressed.

(m) The Commission recommends that plans should be prepared in advance to avoid severe and long-term consequences following a nuclear accident. Such preparedness plans should comprise a set of consistent protective actions, adapted to local conditions at nuclear sites, taking into account the societal, environmental, and economic factors that will affect the impact of the accident and its response.

1. INTRODUCTION

1.1. Background

(1) Nuclear accidents are managed according to guidance covering short-, medium-, and long-term protective actions. In the past, the Commission has set out general principles for implementing protective actions in such situations. The first guidance was issued in *Publication 40* (ICRP, 1984) but was confined to short- and medium-term actions. This guidance was then revised and complemented in *Publication 63* (ICRP, 1991b) in light of the 1990 Recommendations (ICRP, 1991a). In *Publication 82* (ICRP, 1999), the Commission addressed the protection of the public in situations of prolonged radiation exposure.

(2) Building on the experience from managing the Chernobyl accident in Europe, the Commission published guidance dealing with short- and medium-term actions in *Publication 109* (ICRP, 2009a), and long-term actions in *Publication 111* (ICRP, 2009b). The latter publication represented the first comprehensive ICRP recommendations dealing with the long-term actions after a nuclear accident. Both publications were based on the 2007 Recommendations (ICRP, 2007).

(3) Following the Fukushima nuclear accident in March 2011 in Japan, the Commission identified a preliminary set of issues relevant to implementation of the system of radiological protection of people and the environment in the case of a large nuclear accident (ICRP, 2012b). These issues included: difficulties related to the quantification of exposures; interpretation of potential radiation-induced health effects; ad-hoc protection of responders; societal impacts of the evacuation of people; recognising the importance of psychological consequences; and challenges related to the rehabilitation of living conditions in contaminated areas. The present publication is intended to address these issues, together with the lessons learned during the decade following the accident.

(4) In November 2011, the Commission, in co-operation with Japanese organisations, initiated a series of dialogue meetings in Fukushima Prefecture on the rehabilitation of living conditions after the Fukushima nuclear accident with: local residents; professionals; representatives of villages, towns, Fukushima Prefecture, national agencies, and non-governmental organisations; and experts and residents from Belarus and Norway (ICRP, 2016; Lochard et al., 2019; NPO Fukushima Dialogue, 2020). The objective of these dialogue meetings was to facilitate discussions between stakeholders, transfer experience from communities affected by the Chernobyl accident, improve understanding of the challenges in order to support all those involved in the post-accident recovery, and improve future ICRP recommendations. The dialogue meetings highlighted the wide diversity of human and environmental consequences of the accident, its indirect societal and economic impacts, the influence of early decisions on evolution of the situation, the complexity of the return of evacuees and resumption of agricultural and fishery activities, the disturbances to daily life caused by radiological restrictions, the crucial role of engaging stakeholders, and the importance of respecting the dignity of affected people (Ando, 2016).

1.2. Scope and structure of the publication

(5) This publication focuses on the protection of people and the environment in the case of a large nuclear accident. In light of the experience of the Chernobyl and Fukushima nuclear power plant accidents, it reviews the health, societal, environmental, and economic consequences of such large accidents, and updates the way in which the radiological protection principles recommended by the Commission should be applied in these types of situations. A large nuclear accident results when there are significant releases of radioactive material into the environment, impacting widespread areas and affecting extensive populations (IAEA, 2008). Many of the recommendations in the present publication may be applicable to other types of radiological emergencies, including malicious acts, with due consideration of the differences that inevitably exist between a large nuclear accident and these emergencies. The Commission has addressed the protection of people in the event of malicious acts involving radiation in *Publication 96* (ICRP, 2005).

(6) The present recommendations acknowledge the key role of both radiological and non-radiological factors in managing the consequences of a large nuclear accident. They emphasise the importance of the justification of decisions of protective actions during the early phase of a nuclear accident, notably related to the sensitive issues of evacuation of populations and the protection of responders. They address the termination of these actions, and the crucial role of characterisation of the radiological situation for managing the intermediate and long-term phases.

(7) These recommendations also emphasise the importance of the optimisation of protection for the rehabilitation of living and working conditions in the affected areas during the intermediate and long-term phases. They underline the role of co-operation between authorities, experts, and the affected population in the co-expertise process to facilitate informed decisions about their own protection. This process also facilitates the emergence of a radiological protection culture among local communities. Furthermore, the recommendations clarify the ethical, societal, and environmental dimensions to be considered when implementing protective actions.

(8) Section 2 deals with general considerations concerning the timeline of a large nuclear accident, its potential radiological and non-radiological consequences, and the relevant radiological principles for the protection of people and the environment. Section 3 describes the Commission's recommendations that apply to the early and intermediate phases. Section 4 describes those applying to the long-term phase. Section 5 provides a short overview for preparedness planning, and Section 6 gives concluding remarks. In the context of the present recommendations, Annexes A and B describe how protective actions were implemented in the early, intermediate, and long-term phases of the Chernobyl and Fukushima accidents.

(9) This publication updates and supersedes *Publications 109* and *111* (ICRP, 2009a,b). It also supersedes the recommendations published previously in *Publications 40*, *63,* and *82* (ICRP, 1984, 1991b, 1999).

2. GENERAL CONSIDERATIONS

2.1. Timeline for managing a nuclear accident

(10) For managing a large nuclear accident, it is convenient to distinguish between early, intermediate, and long-term phases. In the 2007 Recommendations (ICRP, 2007), the Commission introduced three different types of exposure situation: existing, planned, and emergency. For implementation of the system of radiological protection in the case of a nuclear accident, the Commission considers the early and intermediate phases as emergency exposure situations, and the long-term phase as an existing exposure situation. The Commission recognises that various international and national organisations have adopted different wording or subdivisions to describe the timing of an accident and its management (IAEA, 2018). It is up to the implementing organisation to choose the most appropriate terminology according to national considerations.

(11) The early phase of an accident, sometimes called the 'acute phase', 'urgent response phase', or simply 'emergency response', starts with the declaration of the accident. During this phase, major radioactive releases into the environment occur. These releases can last from a few hours to a few weeks. Depending upon the type of accident, there may be a period of time between the declaration of the accident and the beginning of radioactive releases. It is during the early phase that various protective actions need to be taken promptly in order to avoid or reduce radiation exposures.

(12) The intermediate phase, sometimes called the 'transition phase', starts when the source of the release has been stabilised and further significant accidental releases are unlikely. During this phase, some protective actions implemented during the early phase are discontinued, and additional actions are implemented to further reduce radiation exposure. The focus is also on characterising the radiological situation on-site and off-site in order to decide the best course of action to protect people and the environment. This phase may last from a few months to 1 year or more.

(13) The long-term phase of an accident, often called the 'recovery phase', begins on-site when the radiation source is considered to be sufficiently secured, and the exposure situation is adequately characterised to enable work to begin on dismantling the damaged installation. Off-site, the long-term phase begins when radiological conditions in affected areas are sufficiently characterised to support decisions by the authorities about the future of these areas, and also when long-term protective actions have been implemented to accompany the rehabilitation of living conditions in areas where people are allowed to stay or expected to return. Living conditions include health, societal, environmental, and economic considerations. The long-term phase of large accidents may last from several years to decades.

(14) The shift from one phase to the next is a matter of decisions depending on many factors. In practice, it is generally formalised by an official declaration by the authorities. Fig. 2.1 summarises the timeline of a large nuclear accident. The transition from an emergency exposure situation to an existing exposure situation does not necessarily take place at the same time in all affected areas.

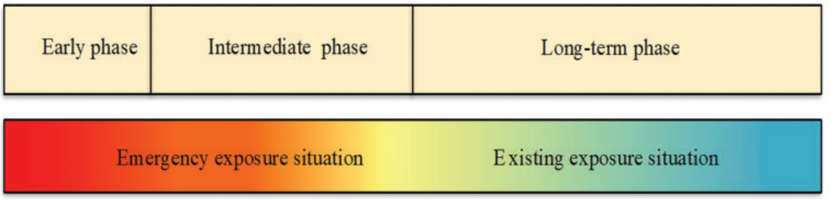

Fig. 2.1. Phases for managing a large nuclear accident.

2.2. Consequences of a large nuclear accident

(15) Large nuclear accidents affect all dimensions of individual and social life. First and foremost, the presence of radiation is the major source of concern for people given the potential health impacts of radiation, which is reinforced by its unknown character. Other impacts may also present immediate and serious risks depending upon the situation. Past experience has revealed that all aspects of daily life of the inhabitants and the environment, including all social and economic activities, are affected, generating very complex situations (UNDP/UNICEF, 2002). These situations cannot be managed with radiological protection considerations alone, but must also take into account the social, psychological, environmental, educational, cultural, ethical, economic, and political factors associated with the consequences of the accident. In this respect, the Chernobyl and Fukushima accidents have shown the importance of giving particular attention to the protection of some vulnerable groups, particularly pregnant women, children, people with regular/specific medical care, and elderly people.

2.2.1. Radiation-induced health effects

(16) The Commission considers two key categories of radiation-induced health effects: tissue reactions leading to tissue/organ damage (also called 'deterministic health effects'), and cancer and heritable diseases (also called 'stochastic health effects').

2.2.1.1. Tissue reactions

(17) Tissue/organ damage associated with radiation exposure is characterised by a threshold dose above which the severity of effect increases with the level of exposure, and below which the reaction is assumed to occur with less than 1% incidence. Such damage may occur soon after exposure (hours to months) or after a considerable time (a few years or even decades), and may severely impair the quality of life of exposed individuals. Table 2.1 shows threshold doses for selected tissue reactions. More details can be found in *Publication 118* (ICRP, 2012a).

(18) Acute organ doses up to approximately 100 mGy produce no immediate functional impairment of tissues. However, after acute or accumulated doses

Table 2.1. Dose thresholds for selected tissue/organ damage. Information given in parentheses indicates timeline of occurrence of effect.

Effect	Threshold
Fatality (within weeks)	2–3 Gy acute dose to the whole body with good medical care 4–8 Gy protracted over 1 week 10–14 Gy in 1–3 months assuming good medical care
Skin burn on large areas (2–3 weeks)	5 Gy acute dose to the skin
Permanent sterility (males) (3 weeks)	6 Gy acute dose to the gonads
Permanent sterility (females) (<1 week)	3 Gy acute dose to the ovaries
Increased risk of circulatory disease (>10 years)	0.5 Gy to the heart or brain
Cataract induction (>20 years)	0.5 Gy to the lens of the eye

above 500 mGy, the severity of tissue reactions becomes increasingly important, particularly for the lens of the eye and the circulatory system, at very long times after exposure. At higher doses, the severity of tissue reactions becomes increasingly important and serious damage may occur, as illustrated by the Chernobyl accident.

(19) Several epidemiological studies, including cohorts of patients treated by radiotherapy, survivors of the atomic bombs in Hiroshima and Nagasaki, and nuclear workers, indicate an increased risk of mortality from circulatory disease associated with doses of several hundreds or thousands of milligrays to the heart (Little et al., 2012). The situation at lower doses is less clear. The Commission has recommended that a threshold dose of 500 mGy is appropriate to protect against radiation-induced circulatory disease (ICRP, 2012a).

2.2.1.2. Cancer and heritable diseases

(20) Cancer and heritable effects are characterised by an increase in the probability of occurrence proportional to the dose, while their severity is independent of the dose received. For the purpose of radiological protection, the Commission assumes that the probability of occurrence of these effects is proportional to the level of exposure (i.e. even small exposure doses might result in a slight increase in risk) (ICRP, 2007).

(21) Increased risk of cancer was reported in many epidemiological studies of exposed populations, such as the atomic bomb survivors in Hiroshima and Nagasaki, and studies of environmental, medical, and occupational radiation exposures. These studies showed that the risk of cancer (i.e. the frequency of cancer cases) was higher among exposed individuals compared with unexposed individuals with similar characteristics (UNSCEAR, 2006).

(22) There is reliable scientific evidence that radiation exposure can increase the probability of cancer occurring in an exposed population. Large uncertainties remain about health effects associated with low-dose and low-dose-rate radiation exposure, but the epidemiological evidence of a dose–risk relationship below 100 mSv is increasing, notably from large studies. Today, much of the available data are broadly supportive of the linear-non-threshold model (NCRP, 2018a; Shore, 2018). Based on the results of epidemiological studies, it is estimated that a dose of 100 mSv above the natural background level adds approximately 0.5% to the 25% lifetime risk of fatal cancer typically seen in populations worldwide (ICRP, 2007; Ogino and Hattori, 2014).

(23) The thyroid gland may be irradiated from external sources (external exposure), but may also accumulate radioactive iodine through inhalation or ingestion (internal exposure). A nuclear accident may result in the release of a large amount of radioactive iodine, leading to substantial exposure of the thyroid in the population. After the Chernobyl accident, the incidence of thyroid cancer increased in the population of infants or young children exposed to radioactive iodine. The increase was observed from approximately 3 years after the accident, and an excess is still observed today among those who were exposed as infants or young children at the time of the accident (UNSCEAR, 2018).

(24) There is no direct evidence that exposure of humans to radiation leads to excess heritable disease, but heritable (genetic) effects have been seen in animals. Therefore, the Commission prudently continues to include the risk of heritable effects in its system of radiological protection.

2.2.2. Consequences for fauna and flora

(25) In the case of severe radioactive releases to the environment, nuclear accidents have the potential to cause direct radiation exposure detrimental to non-human biota in the immediate area surrounding the facility. Damage to fauna and flora was seen after the Chernobyl accident, ranging from the death of forests and a reduction in the number of soil invertebrates, to reports of genetic changes in some species (UNSCEAR, 2000, 2011; IAEA, 2006). Over time, there have been changes in biodiversity, linked to a variety of factors, including the lack of human activity. Although the presence of radioactivity in the environment after a nuclear accident is a concern, in most cases, any direct observable effects on the environment would tend to be limited to the area where the deposition of radioactive material was greatest (UNSCEAR, 2013).

(26) Implementation of protective actions to mitigate the impact of the accident on people is also likely to reduce the exposure of some types of flora and fauna. Moreover, environmental effects on an ecosystem may arise from the implementation of protective actions taken, such as removal of topsoil or tree cover, or the use of chemical ameliorants. In its recommendations on protection of the environment under different exposure situations (ICRP, 2014), the Commission states that although environmental impacts may not be an immediate priority during the

early phase of a nuclear accident, the environmental consequences of protective actions should be considered when choosing options to protect humans in the intermediate and long-term phases.

2.2.3. Societal consequences

(27) The sudden presence of radioactive contamination is perceived as undesirable, illegitimate, and dangerous, and generates a desire to get rid of it. This presence in the living environment of humans profoundly upsets the well-being of individuals and the quality of life of affected communities. It raises many questions, concerns, and fears; generates numerous views; and worsens conflicts. Some residents will choose to stay in affected areas, when this is allowed, and others will leave. Among those who leave, some will return and others will relocate permanently. This can significantly affect community life and demographics, with a notable decrease in the number of inhabitants, especially young people, as illustrated after the Chernobyl and Fukushima accidents.

(28) Management of the accident itself, on-site and off-site, inevitably affects lifestyles and relationships between affected people. This introduces societal repercussions such as organisation of the working and living conditions of responders, accommodation for displaced people, zoning of areas, various restrictions associated with implementation of protective actions, side effects of decontamination, and implementation of a compensation system.

(29) All individuals face a complex situation that raises many dilemmas, and their responses depend on the general situation in their communities and their personal situation. Social infrastructures and activities, such as education, transport, health care, community support, public space, information, public safety, sport, recreation, and art and culture, are all affected.

(30) The Chernobyl and Fukushima nuclear accidents had similar consequences in terms of the societal impacts of the presence of radioactive contamination in affected areas. Beyond the widespread fear of radiation in all sectors of the population, sociological studies have also revealed: a collapse of trust in experts and authorities; disintegration of families and social ties; apprehension about the future, particularly for children; and a progressive feeling of loss of control over everyday life. All of these consequences affect the well-being of people and pose a threat to their autonomy and dignity.

(31) In the longer term, even when affected people understand how to deal with the radiological situation and regain their autonomy and livelihoods, the fear of being abandoned by the authorities and the rest of the country, and the negative image of affected areas, remain problems that constrain social dynamics. A nuclear accident also has societal consequences in areas that are not affected directly by contamination. Managing the reception of evacuees, especially in the early phase, presents organisational and human challenges. Past experience has shown that a nuclear accident generates an attitude of rejection towards affected areas, as well as the people living there and any goods produced there. This attitude has been observed

to cause discrimination, notably against young people (Sawano et al., 2018). In this context, it is important to rebuild and maintain solidarity between affected people and the rest of the country and the world.

2.2.4. Economic consequences

(32) Following a large nuclear accident, the whole economic fabric of affected areas is impacted either directly or indirectly. For example, the agricultural sector is significantly disturbed due to contamination of soil and livestock, affecting food production as well as its distribution and consumption. The accident also has consequences for the industrial and service sectors in affected areas. With the global nature of economics, impacts may be seen nationally and internationally.

(33) Radiological contamination is likely to affect critical infrastructure directly, such as utilities, public transportation, communication systems, and food and water supplies. This has an impact on local businesses and employment, as well as key public services such as government services, security institutions, medical facilities, financial systems, public health services, and education facilities.

(34) Companies hoping to maintain their economic activity in affected areas or those newly operating may face additional obstacles related to the presence of contamination. Staff, workplaces, products, and the image of these companies can all be affected. Experience has shown that it is important to involve both the employees and their families when providing response information and monitoring. Change in the local demography is another factor influencing the overall economy of affected areas.

(35) The economic consequences of an accident can induce additional technical and financial constraints on all economic activities within or connected to an affected area. Maintaining or restarting activities, and developing new ones, needs to be supported by local and national government for several years. For the areas where the authorities decide to allow people to live permanently if they wish, the overall objective is the sustainable redeployment of socio-economic activities in the affected territories.

2.2.5. Psychological consequences

(36) A large nuclear accident can be expected to be very disruptive to people's lives, both in the immediate response and in the longer term as the focus shifts to the rehabilitation of living and working conditions in the affected areas. An accident generates many concerns and considerable fear. People are destabilised by the complexity of the situation and have many questions. Beyond the direct consequences of the accident, there are also societal and economic disturbances that impact people's mental well-being. In addition, people affected by a nuclear accident can feel anguish, dismay, discouragement, helplessness, dissatisfaction, frustration, and anger. Many affected people report feeling a lack of control over their individual living and working conditions, and this is linked to a high level of psychological stress. This situation

can induce psychological and psychosomatic disorders in some people, not correlated with the actual magnitude of radiation exposure, as reported by several studies following the Chernobyl and Fukushima nuclear accidents (Yasumura et al., 2012; Kunii et al., 2016; Oe et al., 2016a,b).

(37) These studies reported an elevated rate of depression and post-traumatic stress disorder among the responders who were directly confronted by the disaster scene, potentially inducing a threat to their lives. Studies have also reported that people who are confronted with radioactive contamination in their daily lives, even if only a small amount, and evacuees facing poor living conditions with no clear view about their future are more vulnerable to anxiety, stress, and depression (Bromet et al., 2011; Bromet, 2014; Harada et al., 2015; IAEA, 2015a; Suzuki et al., 2015; Maeda and Oe, 2017).

(38) Parents with young children who have lingering worries about the potential adverse health effects on the children and their families are particularly vulnerable to psychological disorders. Studies have revealed that anxiety among mothers generated by the presence of contamination in their daily life is a strong stress factor that can induce inappropriate behaviour (lack of sensitivity or even violence), which can hinder the emotional and social development of their children (Maeda and Oe, 2014).

(39) Experience has also shown that, at a psychological level, the response of each individual is highly dependent on his/her own situation and can evolve over time: some people may suffer with depression, others may resign themselves to the situation and eventually adopt an attitude of indifference or denial, and others may react and engage in actions to improve the situation for themselves and others. The psychological effects of a nuclear accident may continue to impact those affected for a long time.

2.2.6. Health impacts of changes in lifestyle associated with protective actions

(40) In addition to radiation-induced health effects following the accident, there may be other health-related impacts due to changes in lifestyle attributable to the presence of radioactivity and the actions taken to avoid radiation exposure. Many studies carried out following the Chernobyl and Fukushima nuclear accidents have reported a range of physical and psychological disorders linked to the protective actions taken not only during the early phase, but also during the intermediate and long-term phases (Hasegawa et al., 2015; Luccioni et al., 2016).

(41) Shortly after an evacuation, vulnerable populations such as patients in hospitals and the elderly in care homes are particularly susceptible to hypothermia, dehydration, and the worsening of pre-existing conditions. These can lead to increases in mortality (Morita et al., 2017). Meanwhile, children living in evacuation centres are more prone to infectious diseases due to overcrowding and stress caused by inadequate facilities. They can also be affected psychologically, with the subsequent development of emotional problems (Oe et al., 2018). Verbal abuse and bullying of evacuated children can form an additional source of stress (Sawano et al., 2018; Oe et al., 2019).

(42) In the intermediate and long-term phases, those who remain in the contaminated areas, as well as those subject to temporary relocation, can experience a range of long-lasting physical health effects due to their changes in lifestyle, including obesity, diabetes, cardiovascular and circulatory diseases, hypertension and chronic kidney disease due to poor diet (e.g. lack of fruit and vegetables), lack of exercise, substance abuse, and restricted access to medical facilities or opportunities to seek treatment. Furthermore, restrictions on outdoor play due to the presence of radiation can lead to higher levels of obesity in children (Nomura et al., 2016; Ono et al., 2017; Tsubokura, 2018).

2.3. Principles for protection of people and the environment

(43) The aim of the Commission's recommendations concerning large nuclear accidents is to advise on actions to be taken to ensure an appropriate level of radiological protection for people and the environment. This means managing human exposures so that severe tissue/organ damage is prevented, the risks of cancer and heritable diseases are reduced to the extent that is reasonably achievable, and the frequency of deleterious radiation effects on non-human biota is prevented or reduced. These objectives should be pursued considering the potential adverse effects of radiation exposure on humans, fauna, and flora, as well as the societal, environmental, and economic consequences of the accident and its management. This means preserving, to the extent possible, the health and well-being of all affected individuals, decent working conditions for responders, quality of life of affected communities, and biological diversity in affected areas.

(44) In emergency and existing exposure situations, the objectives of radiological protection are achieved using the first two fundamental principles of radiological protection: the justification and optimisation principles [see Para. 203 in *Publication 103* (ICRP, 2007)]. The principle of justification ensures that decisions regarding the implementation of protective actions result in a benefit for affected people and the environment, as these actions can potentially induce significant disruptions. The principle of optimisation of protection, applied with reference levels, aims to limit inequity in the distribution of individual doses, and also to maintain or reduce all exposures to as low as reasonably achievable, taking into account societal, environmental, and economic factors.

(45) The third fundamental principle of radiological protection, namely the application of dose limits, is not appropriate in emergency and existing exposure situations following an accident. This principle only applies in planned exposure situations when the source has been introduced deliberately and exposures are fully under control and regulated. In this context, the Commission has defined a framework based on risk considerations to set up dose limits (ICRP, 1991a). The dose limit corresponds to the level of risk (i.e. the level of exposure) not to be exceeded on any reasonable basis in the normal operation of the source under

consideration. Exceeding the limit is an indication of a failure in the operational management which needs to be corrected.

(46) In an emergency exposure situation, when the aim is to regain control of the source, and in an existing exposure situation, when the presence of the source is unintentional, the levels of exposure might be higher than the limits set for a planned exposure situation. This should not be seen systematically as an indication of failure in the management of these situations. Instead of using the dose limit approach and based on experience, the Commission has defined reference levels to be selected within generic bands of exposure considering the induced risk of radiation as well as the feasibility of controlling the situation (ICRP, 2007).

(47) Once an emergency is declared, decisions on protective actions on-site and off-site should be taken promptly during the early phase to be effective. Given the short time to react and the numerous uncertainties, these actions should be prepared in advance on the basis of plausible scenarios, and adapted as much as possible to the actual situation. Management of the early phase requires adequate interaction between affected countries and international co-operation, notably to address protection of nationals, cross-border issues, food restrictions, and assistance as needed (IAEA, 2015b). During the intermediate phase, progressive characterisation of the radiological situation on-site and off-site is essential to guide decision-making about the protective actions to be initiated, continued, or discontinued. In the long-term phase, radiological situations on-site and off-site are better understood, and can be improved by implementing protective actions fitting the diverse local specificities in the affected areas.

(48) In the early phase, consideration of protection of the environment may not be an immediate priority (ICRP, 2014). However, concerning domestic animals, the Commission recommends that appropriate measures should be taken to protect pets and livestock, and specific arrangements should be developed in the preparedness planning process to preserve their welfare and prevent spread of diseases and contamination.

(49) In the intermediate phase, consideration should be given to the consequences of radiation exposure on fauna and flora, as well as the consequences of the possible protective actions on the environment, even where concerns about human exposure predominate. This is particularly true regarding the choice of actions to decontaminate the environment (e.g. soil), as this is likely to affect the organo-mineral fertility of the soil in the long term and the biodiversity.

(50) During the long-term phase, it should be possible to consider actions to protect species which are likely to be threatened by long-lasting contamination. Special provisions may also be necessary to maintain the quality of the environment impacted by the implementation of protective actions. These actions should be considered within an overall approach, including the abundance and diversity of threatened or endangered species, the spatial extent of the impact, and the inherent value of the environment (NCRP, 2018b).

2.3.1. The justification of decisions on protection

(51) The principle of justification states that any decision altering a radiation exposure situation should do more good than harm. It is part of the ethical values to do good (beneficence) while avoiding doing harm as much as possible (non-maleficence), consistent with ethical values of beneficence and non-maleficence, as explained in *Publication 138* (ICRP, 2018). In emergency and existing exposure situations, the principle of justification is applied when deciding whether to take actions to avoid or reduce potential or actual exposures. All decisions that aim to reduce the impact of exposure in the event of a nuclear accident introduce additional constraints in working conditions on-site and on daily life in affected areas, which have greater or lesser negative effects on the individuals and communities concerned. Decisions should be based on a reasonably realistic but cautious approach, taking into account the inevitable uncertainties of the situation on-site as well as off-site, and bearing in mind their potential negative consequences.

(52) Justification is part of radiological protection which is not just about avoiding or reducing exposure, but may also encompass non-radiological health effects, and societal, economic, and environmental considerations. Justification is in accordance with the overall ethical goal of societies, which is to contribute to the well-being of individuals, the quality of life of affected communities, and the preservation of the quality of the environment for future generations. To contribute to the well-being of individuals, justification should also include special consideration of vulnerable groups or particular communities such as indigenous populations.

(53) Responsibility for making decisions on the justification of protection is usually the role of authorities and responsible organisations. The aim is to ensure an overall benefit, in the broadest sense, to society and not necessarily to each individual. However, there are many aspects of the justification of decisions that can be usefully informed by organisations or individuals outside the authorities. Therefore, the Commission recommends involving key stakeholders in public processes for the justification of decisions whenever possible (NEA, 2006).

(54) The Commission considers that the justification of decisions should be re-assessed regularly as the overall situation resulting from the accident evolves. Therefore, justification is not a 'one-off' consideration taken during planning or during the management of the accident. It should question whether the decisions already taken continue to do more good than harm in the broadest sense. The Commission also considers that justification of the overall protection strategy should address the harm and benefit of protective actions applied singly or in combination. It should ultimately be judged by balancing the level of residual exposure of affected people with the societal, environmental, and economic effects.

(55) In the early phase, justification applies to the decisions on whether or not to take prompt actions to avoid or reduce exposures. In this context, the evacuation and sheltering of people are the most delicate decisions. Although these actions are effective and relatively straightforward for protecting small communities, they are disruptive and potentially difficult to implement on a large scale for a long duration.

Lessons learned from the Fukushima accident, for example, suggest that the unplanned evacuation of elderly or medically supervised people from nursing homes may have caused more harm than good for these people (Tanigawa et al., 2012). Similarly, strict sheltering may not be justified for periods extending beyond 1 or 2 days (see Section 3 for more details). The need to act quickly is not conducive to stakeholder involvement. However, stakeholders should be involved in preparedness planning and exercising.

(56) In the intermediate phase, justification applies to decisions on implementing further protective actions with the perspective that these actions combined together constitute a coherent protection strategy. Justification also applies to the fundamental decision of authorities concerning the future of the affected areas, and marks the beginning of the long-term phase. This decision has to be taken in co-operation with affected individuals and local communities once the radiological situation is better characterised, taking into account the results of the protective actions already implemented. This decision should also take into account the information available on the sustainability of societal and economic activities. It is necessary to decide, among other things, the areas where the population is not allowed to stay in view of the high residual levels of exposure and the difficulty to maintain suitable living and working conditions, and the areas where, given the exposure situation, people are allowed to live permanently if they wish to do so. Several geographical areas can be defined for which ad-hoc protective actions can be implemented according to a graded approach depending on the expected level of exposure, as well as societal, environmental, and economic considerations. This was the approach adopted by the authorities after the Chernobyl and Fukushima nuclear accidents.

(57) Worldwide experience after nuclear and other industrial accidents that led to large and long-lasting contamination, or natural disasters, shows that nations and individuals are not willing to abandon affected areas readily (Bonaiuto et al., 2016). However, the decision to allow people to stay in affected areas should only be taken when the necessary conditions are met, particularly protection against the potential health consequences, and the achievement of suitable living and working conditions, including sustainable lifestyles and livelihoods. Past experience has demonstrated the importance and benefit of involving stakeholders in these decisions, particularly representatives of local authorities, professionals, and inhabitants of affected communities, to improve the decision-making process.

2.3.2. The optimisation of protection

(58) Once decisions have been taken to protect people and/or the environment, the Commission recommends that protective actions should be implemented in accordance with the principle of optimisation of protection. This central principle of the radiological protection system means that all individual exposures should be kept as low as reasonably achievable, taking into account societal, environmental, and economic factors.

(59) Implementation of the principle of optimisation of protection is a process that requires good understanding of the exposure situation, including the various factors at stake, and the relevant radiological information and data characterising this situation in order to choose the best protective actions given the particular circumstances. Furthermore, it should reflect the views and concerns of stakeholders, and the ethical values that govern radiological protection [i.e. to avoid unnecessary exposure (prudence), fair distribution of exposure among exposed individuals (justice/equity), and treating people with respect (dignity)]. Prudence, justice/equity, and dignity are universal core ethical values that underlie the system of radiological protection, particularly the optimisation principle (ICRP, 2018).

(60) Implementing the optimisation principle is a step-by-step process that aims to select the best protective actions given the characteristics of the exposure situation (see Fig. 2.2).

(61) Comparison of justified protective actions is a key feature of the optimisation process, which must entail careful consideration of all the characteristics of the situation. Decision-aiding techniques may be used to guide the selection of protective actions. Advice on applying these techniques has been provided in *Publications 37*, *55*, and *101* (ICRP, 1983, 1990, 2006). Due to its judgemental nature, there is a strong need for transparency and direct involvement of stakeholders concerned with the exposure situation. This transparency assumes that all available and relevant information, assumptions, and judgements about the radiological and non-radiological impacts are provided to affected people, and that the traceability of the decision-making process is documented properly, providing evidence for an informed decision (ICRP, 2006, Para. 34).

(62) Optimisation is a frame of mind, questioning whether the correct set of actions has been taken in the prevailing circumstances, and if all that is reasonable has been done to maintain or reduce exposures to as low as reasonably achievable. It is the authorities' responsibility to provide good guidance and adequate support to

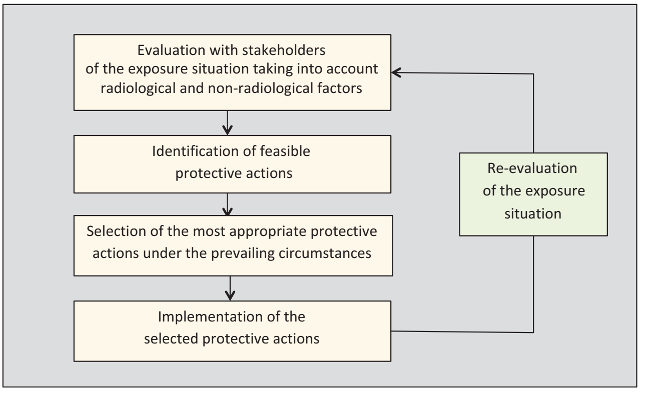

Fig. 2.2. The optimisation process.

organisations (e.g. in the agricultural and industrial sectors) and individuals (with responsibilities or concerned citizens) involved in the practical implementation of protection. Hence, the government, or the responsible authority, needs to constantly evaluate the effectiveness of the protective actions in place, including those performed at local or individual levels, in order to provide adequate support for their implementation.

(63) As with the justification of decisions, the practical implementation of optimisation during the early phase is hampered by uncertainties and a lack of information about the radiological situation on-site and off-site. Assumptions should also take into account non-radiological consequences, given uncertainties such as the conditions of infrastructures or the reaction and behaviour of the population. For these reasons, protective actions that were considered justified in preparedness planning are initially implemented. As characterisation of the radiological situation progresses, it is possible to revisit the optimisation process for the various protective actions implemented in order to better take into account the particularities of the exposure situations, both on-site and off-site.

(64) Due to the complexity of the socio-economic situation resulting from a nuclear accident, the implementation of optimisation during the early, intermediate, and long-term phases should recognise the many value judgements concerning the importance or the priority to be given to protection of vulnerable or particular groups of the population, or to social and economic activities. This includes paying due attention to, for example, pregnant women, children, and the elderly and infirm. Strategic social and economic activities should also be the subject of specific protection provisions in implementing the optimisation process.

(65) The optimisation process inevitably has to cope with conflicts of interests among stakeholders, and must seek to reconcile their different expectations and needs. For example, producers of goods, services, and food wish to continue production, but their ability to do so is affected by the willingness of consumers to purchase these items. Another example is the desire of affected people to continue to interact with national and international populations, such as through tourism, while those populations may be unwilling to do so. Thus, protective actions should contribute to the confidence of all people in relation to the affected area.

(66) One of the characteristics of radiation exposure in the event of an accident is the large distribution of exposures received by responders, and also by people living and working in the affected areas. Past experience shows that the majority of people receive relatively low exposures, although doses to a fraction of the affected individuals may be more significant. During the early phase, a few people may receive high exposures that could induce severe radiation health effects if protective actions are not implemented promptly. The Commission therefore pays particular attention to equity in the distribution of exposures within the groups of affected people, and recommends that, in the event of an accident, optimisation of protection should be implemented with the aim of reducing the exposure of the most exposed individuals as a priority.

(67) In the case of an accident, the protection of vulnerable people is also a concern. Notably, pregnant women and young children are more sensitive to radioactive iodine exposure. The health status of elderly people, as well as sick and/or hospitalised people, may also be particularly affected by the disturbances due to the event and the protective actions. Homeless people may also receive more exposure because of their poor living conditions (Sawano et al., 2019). Therefore, the Commission recommends the identification of vulnerable groups and their consideration in the implementation of the principle of optimisation.

(68) In order to reduce individual exposures and limit inequities in the distribution of exposures, the Commission recommends using reference levels to guide the optimisation of protection during the successive phases of a nuclear accident. These reference levels have to be adapted to the different phases of the accident by distinguishing between the exposure of responders on-site, responders off-site, and members of the public off-site (see Section 3.3). The Commission also recommends using the residual dose to assess the effectiveness of the protective actions implemented. This residual dose corresponds to the remaining dose added by the accident without including the natural background exposure. As the best protective action is always specific to the exposure situation, it is not relevant to determine, a priori, a dose level below which the optimisation process should stop (ICRP, 2007, Para. 218). Optimisation of protection, however, is not minimisation of exposures. It is the result of a process that carefully balances the reduction of exposures with the associated societal, environmental, and economic impacts. This does not always result in the lowest residual dose level for individuals.

(69) Once the intermediate phase is over and the radiological situation has been characterised, a more detailed optimisation process can be implemented step by step, taking due account of the local conditions, adapting the protective actions as the radiological situation evolves, and including the concerns and wishes of individuals and local communities. As the number of measurements of radioactivity in the environment and of individual exposure increases, it becomes possible to identify which people remain the most exposed and the factors contributing to their exposure. The implementation of targeted protective actions progressively contributes to reducing the highest exposures, as well as the average exposure of the population. In the longer term, experience has demonstrated that, in areas where people are allowed to live, it is generally possible to reduce the exposure of most people to levels comparable with those considered as tolerable for public exposure due to man-made authorised radiation sources in non-affected areas.

(70) During the intermediate and long-term phases, the exposure of individuals depends not only on the residual radiological situation in the area where they reside and work, but also, to a large extent, on their behaviour and lifestyle (e.g. diet, leisure activities, etc.). Behaviour and lifestyle largely depend on individual circumstances, resources available, and willingness and ability of the individuals to make changes. Once individuals are properly informed about the contributions to their exposure, they are able to make choices and take action about their lifestyle and habits to further reduce their exposure. The Commission calls these types of actions 'self-help

protective actions', and considers their implementation to be an integral part of the optimisation process that can be very effective and should be supported and encouraged by the authorities and experts.

(71) As radiological protection assumes that the probability of stochastic effects is proportional to exposure, the dilemma for individuals in the long-term phase is to balance the effort and consequences of adopting self-help protective actions with the residual radiological risk that might be present. Furthermore, there is generally a limitation to what individuals can achieve without unreasonably altering their behaviour and restraining their desires. Such decisions can only be made with relevant information about the radiological situation and access to individual measurements.

(72) Authorities and experts should facilitate processes to allow inhabitants and local communities to define, optimise, and apply self-help protective actions, if they wish to and can do so, by answering questions, assisting in measurements and in interpretating results, and providing information and support (see Section 3.4.3 on the co-expertise process). However, self-help protective actions may also be disruptive (e.g. paying constant attention to food consumed and places visited in order to reduce internal and external exposures).

(73) A strategy for implementing protective actions should be prepared by the authorities as part of national preparedness and planning arrangements. These plans should take self-help protective actions into account, including the conditions to enable such actions to be undertaken by the inhabitants. Although it is difficult to predict the success of protective actions to reduce exposure, and to ask the population to plan for such actions, the Commission recommends that authorities should involve representative stakeholders in the preparation of these plans.

2.3.3. Optimisation and the use of reference levels

(74) For the protection of people in emergency and existing exposure situations, the Commission recommends using reference levels, expressed in terms of individual effective dose (mSv), to restrain inequity in the distribution of exposures, and to maintain or reduce all exposures to as low as reasonably achievable. In preparedness planning, before any accident occurs, reference levels are used as guiding values to select and scale the protective actions that should be implemented in the early, intermediate, and long-term phases for a given type of accident scenario. Therefore, they represent, at the planning stage, the exposure levels not to be exceeded. When an emergency exposure situation has occurred or an existing exposure situation has been declared, reference levels become a benchmark for evaluating the effectiveness of protective actions. Initially, the distribution of exposures resulting from these actions may or may not include exposures above the reference level, depending on the circumstances. The objective is to further reduce exposures, with an emphasis on reducing those above the reference level to below it.

(75) The Commission maintains its position that reference levels do not constitute prescriptive regulatory limits that should not be exceeded. In practice, reference levels may be exceeded by some individuals at the start of, or during, the

optimisation process without this constituting any regulatory violation. As such, reference levels guide the practical implementation of the optimisation principle, and are tools that may be incorporated into international and national guidance. *Publication 103* (ICRP, 2007) has provided bands of generic reference levels from which specific reference levels can be selected, taking into account the characteristics of the exposure situations considered.

(76) Fig. 2.3 illustrates schematically how reference levels are guiding the optimisation process in all phases of a nuclear accident. At the beginning of each phase, a fraction of the individual exposures may be above the reference level selected by the authorities. A priority should be to identify the most exposed people (potentially or actually) in order to prevent or reduce their exposure. The protective actions implemented during the successive phases should progressively reduce the number of people receiving exposures above the reference level.

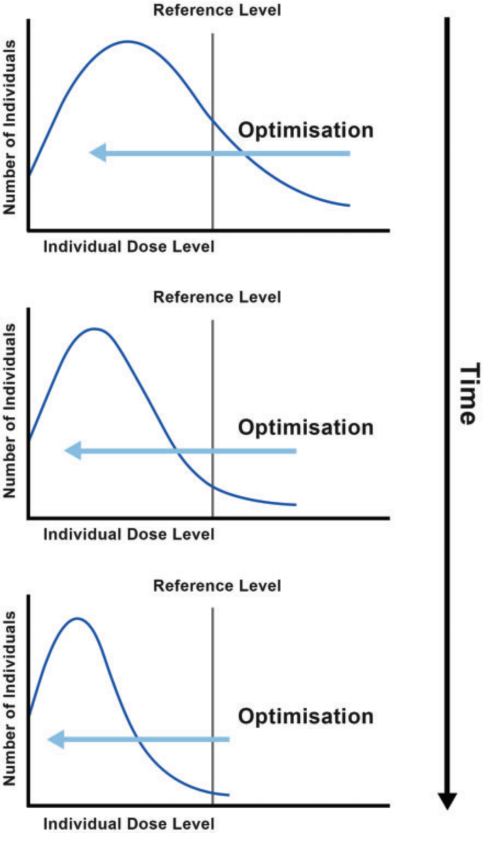

Fig. 2.3. Schematic illustration of the evolution of the distribution of individual exposures with time as a result of implementing the optimisation process with a reference level.

(77) When conditions evolve and the dose distribution changes, it may be appropriate to re-evaluate the reference level. As the number of individuals whose doses exceed or are close to the reference level decreases, the reference level may be lowered to accompany the improvement in the radiological situation. To be effective, the process of selecting and re-evaluating the value of the reference level should be adapted to the circumstances. In addition, the Commission recommends including, where feasible, the views of all relevant stakeholders to decide the level of ambition to be achieved by selecting a given reference level.

(78) For protection of the environment, the Commission recommends the use of derived consideration reference levels (DCRLs) to prevent or reduce the frequency of deleterious effects on fauna and flora in affected areas (ICRP, 2008). DCRLs are defined in terms of a band of dose rates for the Reference Animals and Plants (RAPs) within which there is likely to be some deleterious effects for the considered RAPs. During the early phase of an accident, the protection of fauna and flora is generally not the first priority. However, DCRLs may be useful in understanding the potential impacts on fauna and flora. In the intermediate and long-term phases, when the radiological situation is better characterised, the Commission recommends that consideration should be given to reduce exposures of particularly exposed RAPs, taking into account the societal, environmental, and economic factors.

(79) In this publication, the Commission provides recommendations about implementation of the optimisation principle and selection of the relevant reference levels in the early, intermediate, and long-term phases of a large nuclear accident for the protection of people on-site and off-site, as well as the protection of non-human biota. Details are provided in Sections 3 and 4, respectively.

3. THE EARLY AND INTERMEDIATE PHASES

3.1. Characteristics of the early and intermediate phases

(80) The Commission recommends managing the early and intermediate phases of a large nuclear accident in accordance with the radiological protection principles that apply to emergency exposure situations. These situations, which are defined as resulting from a loss of control of a radiation source or from intentional misuse of a source, require urgent and timely actions to avoid or mitigate undesirable exposure, and regain control of the source. Emergency exposure situations may be characterised by one or more of the following features: significant uncertainty concerning current and future status of the source; uncertainty about pathways and levels of exposure with potential for high levels of exposure; and rapid changes of radiological and non-radiological conditions.

(81) Emergency exposure situations arising from large nuclear accidents result in exposure of responders as well as exposure of the public. This may last for an extended period of time – several weeks or even months as seen in the Chernobyl and Fukushima accidents. Large nuclear accidents may involve one facility, multiple facilities at the same site, or multiple sites if significant external events play a role. During the early phase, it is necessary to act promptly to mitigate the consequences of the radioactive releases. Progressively during the early and intermediate phases, the releases are brought back under control and the radiological situation becomes better characterised. Off-site, there is still uncertainty about exposures and the future for affected areas. Therefore, the intermediate phase may last longer off-site than on-site.

(82) For a large nuclear accident, the highest exposures should generally occur during the early phase when the source is out of control. The Commission recommends that the first priority should be the avoidance of cases of direct severe tissue/organ damage both on-site and off-site. The main urgent protective actions to be considered in the early phase are evacuation, sheltering, iodine thyroid blocking, restrictions on local food and water supply, and protection of pets and livestock. As these actions must be implemented promptly, it is necessary to prepare them in advance, particularly in terms of outlining their practical arrangements and geographic extent (Callen and Homma, 2017).

(83) Protective actions taken before any significant release should be designed to avoid the occurrence of direct serious radiation injuries, and should generally also prevent or significantly reduce radiation exposures (IAEA, 2015b). When deciding about these actions, it is also important to take into account their potential non-radiological impacts and to adapt them accordingly. As the actual situation may be significantly different from the preplanned scenario and may evolve rapidly, there may be a need to adapt the protective actions during the response.

(84) As more information on the radiological situation becomes available during the intermediate phase, it may be necessary to modify the geographical or temporal spread of the initial protective actions, and to introduce new protective actions such

as temporary relocation, foodstuff management, decontamination of the environment, and management of business activities. During this phase, further actions should be undertaken to better characterise the exposure situation in order to identify where, when, and how people are exposed and could be exposed in the future.

(85) During the early and intermediate phases, affected people should be informed by all available channels, including radio, television, text messages, e-mails, and social media, about the situation and its evolution. This information should be spread quickly and continuously, and be updated constantly. Experience from past nuclear accidents has shown that spreading accurate information is not sufficient. Therefore, the Commission recommends promoting co-operation between authorities, experts, and local stakeholders in the co-expertise process to respond to the concerns of the affected people and to help them to take informed decisions.

3.2. Radiological characterisation

3.2.1. Exposure pathways

(86) In the event of a large nuclear accident, external and/or internal exposures result from various pathways. External exposure results from airborne radioactive material present in the plume discharged by the damaged installation, and from radioactive material deposited from the plume on to the ground, buildings, clothing, and skin. Internal exposure results from the inhalation of radioactive material from the plume or resuspended from contaminated surfaces, from the ingestion of contaminated food and water, and from inadvertent ingestion of radionuclides on the ground or objects.

(87) In the case of an accidental atmospheric release, it is likely that initial exposures would be relatively high due to the inhalation of short-lived radionuclides present in the plume. This is usually followed by a time period lasting days or weeks when radioactive iodine dominates internal exposure from direct contamination of crops and transfer to milk, and external exposures occur from contamination deposited in the environment. During the intermediate phase, external radiation is likely to become dominant, together with the long-term contamination of foodstuffs by radioactive caesium.

(88) The pattern of deposition is dependent on the magnitude of the event, and on the prevailing meteorological conditions at the time of the release, particularly wind direction and any rain- or snowfall occurring during passage of the plume. For an extended release, wind direction can be expected to vary over time. In the longer term, rainfall and weathering cause redistribution of radionuclides in the soil and their further migration. Plant uptake of radionuclides from soil varies according to the physical and chemical characteristics of the soil (e.g. moisture and fertility), and generally decreases with time. The levels of deposition may also vary greatly from one area to another. For example, after the Chernobyl accident, surface contamination varied by factors of up to 10–100 within the same village. Generally, in the

longer term, one or a few radionuclides dominate exposures to both human and non-human biota.

(89) Radionuclide intake by humans comes mainly from consumption of vegetables, meat, and milk from contaminated farms; fish from contaminated rivers, lakes, and seas; and wild berries and mushrooms from contaminated forests. The transfer to animals and derived products depends on contamination of feeds and forages, and management techniques. There may be considerable variation in intakes by the population over time depending on dietary habits, while radionuclide concentrations in foods depend on the types of soil and crops being cultivated. Compared with agricultural lands, certain areas may show higher levels of transfer to particular foods (e.g. berries and mushrooms in forests, and livestock grazing upland pasture). Consumption of such foods may give rise to higher ingestion doses in some individuals.

(90) Experience from past accidents indicates that there is the possibility of radiation exposure from aquatic pathways due to the release of liquid radioactive material to the sea or surface waters, deposition of radioactive material directly on to the sea or surface waters, and from run-off into the sea or surface waters. For direct or indirect releases of radioactive material into the sea, people can be exposed externally from radionuclides in the sea or sea sediments. The doses from these pathways are not expected to make significant contributions to overall exposure. Conversely, the transfer of radioactive material into seafood could be a possible primary source of internal exposure for some members of the public.

(91) Animals and plants can receive both external and internal exposures. As with people, external exposure results from airborne radioactive material present in the plume and aquatic releases of radioactive material discharged by the damaged installation, and from radioactive material deposited from the plume on to the ground and biota. Internal exposure results from the inhalation of radioactive material from the plume or resuspended from contaminated surfaces, from ingestion of contaminated water or plants and animals, and from inadvertent ingestion of radionuclides on the ground.

(92) Radionuclide contamination levels and composition should change over time and in different locations, resulting in a range of exposures to non-human biota. Understanding how specific animals spend their time in contaminated areas may also be important, along with the size of the affected population.

3.2.2. Environmental and individual monitoring

3.2.2.1. Environmental monitoring

(93) Environmental monitoring is required to provide an accurate picture of the radiological situation, both on-site and off-site. Predictions of exposure can be made using meteorological information, environmental monitoring data, and modelling. An adequate number of meteorological stations should be available to characterise weather conditions in areas that might be of radiological concern (i.e. from close to

the installation to surrounding areas where deposition may affect inhabited areas or agricultural land). Fixed and mobile radiological monitoring equipment can be used by trained operators to evaluate exposures with more precision. Aerial monitoring also provides useful information on the degree and extent of environmental contamination in the case of widely affected areas (Saito et al., 2019).

(94) In addition to environmental monitoring of ambient dose rates, measurements of radionuclide concentrations in air should be made. This type of information enables the estimation of internal exposure due to the inhalation of radioactivity. Concerns about internal and external exposures arising from deposited radioactive material in the environment require plans for measuring concentrations of radionuclides in surface soil and drinking water to assist decisions on the implementation of both food and water restriction, and extended protective actions (e.g. temporary relocation). The monitoring of soil, food, and water is likely to continue beyond the intermediate phase and into the long-term phase.

(95) Detailed environmental monitoring is essential for understanding the radiological situation of widespread contaminated areas, and for terminating the urgent protective actions implemented during the early phase. As radioactive releases are brought to a halt and more detailed monitoring becomes possible in affected areas, the availability of environmental measurement data increases. In addition to the official measurements made by the organisations responsible for managing the early and intermediate phases, affected stakeholders may want to map their own radiological situation using radiation detectors that they have bought or those made available by local institutions (e.g. universities, local laboratories, etc.). Whilst data collection by stakeholders may start in the intermediate phase, it is likely to assume more importance during the long-term phase. Resources should be preplanned to support such data collection by stakeholders, particularly by helping those affected to understand the relevance of such data to their own radiological situation and to help them make decisions on their own protection.

3.2.2.2. Individual monitoring and health surveillance

(96) In the early phase, triage is important to identify people who need care due to their level of exposure (decontamination, medical treatment) and those who need health surveillance. These decisions are based on limited monitoring information and are concentrated on the identification of those with an urgent need for treatment. In the first few hours, it may only be possible to perform initial screening measurements using, for example, hand-held monitors or portal monitors. Subsequently, more accurate measurements can be made with transportable in-vivo monitoring devices, such as whole-body counters and thyroid monitors. In the days that follow, in-vitro measurements of biological samples (e.g. radionuclides in urine, cytogenetic measurements of blood) or retrospective physical dosimetry (e.g. screen glasses of mobile phones, household salt) can be made to determine exposures.

(97) In the case of radioactive iodine releases, thyroid dose monitoring in the early phase is important for children and pregnant women. Environmental monitoring cannot provide an accurate estimate of individual thyroid exposures. Therefore, a specific effort should be made to urgently monitor radioactive iodine content of the thyroid in children (up to approximately 15 years of age at the time of exposure) and pregnant women to provide realistic estimates of thyroid doses. Thyroid measurements can be made by trained and properly equipped personnel at evacuation centres and post-accident centres established for health surveillance. Given the short half-life of radioactive iodine, it is important to make such measurements within a few weeks of exposure, ideally as soon as practical after exposure. The Commission recommends expressing thyroid exposure in terms of organ dose. Information on thyroid doses should be given to those who are measured, with a clear explanation of what the values may mean for the individual's health.

(98) During the intermediate phase, a whole-body monitor can be used to provide measurements of contamination that was inhaled or ingested by affected people on-site and off-site. This allows the assessment of internal exposure, which can help to identify pathways, mainly foodstuffs, deserving particular attention. Measurements of internal contamination in children, including babies, provide useful information to mothers for understanding their children's situations, and options for adjusting their diets (Hayano et al., 2014). Over time, pathways of exposure can change, and this needs to be considered when prioritising people for whole-body measurements.

(99) Measurement data should be collected centrally and made available as soon as possible to all relevant organisations in charge of managing the early and intermediate phases in order to assist them in making decisions on protection. For the sake of accountability and transparency, the Commission recommends that this information should be shared with members of the public, accompanied by a clear explanation, while respecting the protection of personal information.

(100) Medical monitoring programmes that are focused on people affected by the radiation during the early phase should consider two target groups: people who develop clinical symptoms, and people known to have been exposed but not showing any symptoms. Follow-up in the first group is aimed at diagnosis and treatment of any long-term complications. Follow-up in the second group is aimed at the detection of adverse effects or diseases that are potentially related to radiation exposure.

3.3. Protection of responders during the early and intermediate phases

(101) Individuals who may be involved in the response to an accident are diverse in terms of their status: emergency teams (e.g. firefighters, police officers, medical personnel), workers (occupationally exposed or not), professionals and authorities, military personnel, and citizens who volunteer to help. Different terms have been used to classify these individuals by national and international organisations. In this publication, the Commission considers that the term 'responder' is appropriate to refer to all of these individuals. As the radiological situation generated by the accident has

very little to do with the normal operating conditions of the installation, the protection of responders should be managed in a specific way to take into account the fact that the source of exposure is no longer under control and that the working conditions are unusual. Given the wide range of exposures during the early and intermediate phases, a graded approach is required. Moreover, given the unpredictability of the situation resulting from an accident, this approach should be sufficiently flexible, while remaining cautious, to be effective. In order to organise the protection of responders in the early and intermediate phases, the Commission recommends distinguishing between on-site (damaged installation) and off-site (affected areas) actions, and distinguishing between the two phases.

3.3.1. Protection of responders during the early phase on-site

(102) The first responders to be involved on-site are workers from the damaged plant while waiting for emergency teams. Their role is to implement the initial actions to respond to the accident, stabilise the installation, and mitigate the off-site consequences. In undertaking these initial actions, there is potential for some of these individuals to receive high exposures. Although these responders are still under the responsibility of the operating management, the radiological situation is such that they can no longer be managed according to the planned exposure situation that prevailed before the accident. The workers who are not involved in the response should be protected in the same way as the off-site population under the same circumstances, notably through evacuation or sheltering as well as iodine thyroid blocking, as appropriate. In contrast, those who are involved in the early-phase response should be managed as responders, applying the principles of justification of decisions and optimisation of protection. Depending on the situation, other responders from outside are likely to join in to support the workers from the installation. This may include specialised teams generally working under the responsibility of their own organisations, or workers from other facilities generally acting under the responsibility of the management of the damaged installation. In some circumstances, military personnel may also be mobilised with a special status, which falls within the military organisation.

(103) The justification of decisions that may affect the exposure of responders should be taken in light of the status of the damaged installation and its possible evolution, as well as the expected benefits in terms of avoidance or reduction of off-site population exposures and contamination of the environment. Overall, these decisions should aim to do more good than harm; in other words, they should ensure that the benefit for the individuals concerned and society as a whole is sufficient to compensate for the harm they may cause to the responders. Given the uncertainties that characterise the status of the installation and the off-site environment, it is difficult to assess these benefits, and justification of decisions is inevitably based on value judgements by the operating management.

(104) As the radiological situation of the facility during the early phase may largely be unknown and unstable, implementation of the optimisation of protection

for the responders is complicated. Many tasks are undertaken without being able to estimate a priori the potential consequences for the responders involved. Moreover, as the source causing exposure is largely or totally out of control, it is difficult to predict, with sufficient precision, the exposures that they receive, and to guarantee that the tasks are performed within the pre-established radiological criteria. In such circumstances, the principle of application of dose limits is not suitable for the control of exposures of responders. Instead, the Commission recommends applying the principle of optimisation of protection using reference levels for managing individual doses. These reference levels should be selected taking into account the evolving characteristics of the situation and the type of responders.

(105) As mentioned in Paras 18 and 22, the risk of cancer increases with dose, and there is an elevated likelihood of deterministic effects at exposures higher than 100 mSv (ICRP, 2007). For this reason, the Commission considers that an exposure above 100 mSv incurred either acutely or in 1 year would be justified only under extreme circumstances. Consequently, during the early phase, the Commission recommends a reference level of 100 mSv or below to control exposures of responders. Exposures of a few hundred millisieverts would only be justified in exceptional circumstances in order to save lives or to prevent further degradation of the facility leading to catastrophic conditions. In addition, significant intakes of radioactive iodine may occur. This case should be considered separately, and specific protective actions should be implemented as required (see Section 3.4.1.3).

(106) Exposure of responders during the early phase should be assessed and recorded. Individual protective equipment should be used as necessary. Medical care and subsequent health surveillance should be provided as required, particularly in the case of exposures likely to induce deterministic effects. Pregnant women and young persons aged less than 18 years should not be involved in teams of responders operating on-site during the early phase.

(107) The Commission recommends that decisions concerning the protection of responders should be based on the full characteristics of the exposure situation, and in the context of other hazards that may also be present. It also recommends that some workers in nuclear installations should be trained and prepared before any accident occurs to participate in a dedicated emergency team under the responsibility of the operating management, either at each site or at a national level (Ohsuga, 2012). Participants of such a team should be fully aware of the radiation risks in the case of an accident, and should formally provide their informed consent.

3.3.2. Protection of responders during the early phase off-site

(108) Several categories of responders may intervene off-site during the early phase, including firefighters, police officers, rescue and medical staff, and military personnel. In some countries, dedicated teams have been established to deal with nuclear accidents off-site. Workers with specific skills, such as bus drivers in the case of evacuation, elected representatives, and volunteers may also be involved. All these

responders are either directly or indirectly under the responsibility of the response organisation. Their role is to support implementation of urgent protective actions for the population and the environment. The exposures they are likely to receive may be high, but are expected to be less than on-site.

(109) These responders should be identified, either in advance (i.e. emergency teams) or just before their involvement (e.g. citizens, workers such as bus drivers). Members of emergency teams should be prepared and trained to work with radiation. For responders not identified in advance, who have not been trained, the Commission recommends that they should receive information on the tasks to be undertaken in the presence of radiation and associated risks, and that they should be protected adequately (e.g. by any protective equipment). These responders should intervene knowingly and with informed consent.

(110) Some individuals in nuclear or non-nuclear facilities located in the vicinity of the damaged installation may need to stay at their work location, whatever the circumstances, in order to maintain the operation of vital activities or networks. These workers may be treated as responders. In particular, they should be identified, as much as possible in advance, informed about what should be done in the event of a nuclear accident, and trained to perform their work under appropriate protection.

(111) For the protection of responders off-site during the early phase, the Commission recommends using a reference level of 100 mSv or below to control exposures according to the circumstances. As for protection on-site, exposure of responders off-site above the reference level would be justified only under exceptional circumstances, such as to save human lives or to prevent severe radiological consequences for some groups of the population or animals. The doses should be assessed and recorded for off-site responders on an individual basis, as much as possible. Medical care and subsequent health surveillance should be provided as necessary in the case of exposures likely to induce deterministic effects. Pregnant women and young persons aged under 18 years should not be involved in teams of responders operating off-site during the early phase.

3.3.3. Protection of responders during the intermediate phase on-site

(112) On-site, the intermediate phase starts when the source is declared stabilised (i.e. with no more or just a few releases, and a limited risk of further source deterioration). It finishes when the source is declared secured and the radiological situation is sufficiently well characterised to allow work to start on dismantling the damaged installation under controlled working conditions. During this phase, workers from the plant and contractors may be involved in characterising the situation and regaining control of the source. All workers are generally under the responsibility of the operating management of the damaged installation, while preserving the responsibility of each employer as relevant. As the site is damaged, contaminated, and weakened, the working conditions may be unprecedented and difficult. Any inappropriate action or unforeseen circumstance may result in a new emergency.

Nevertheless, the organisation of work and the management of exposures should be improved progressively. In such circumstances, workers are still considered as responders, although the management of their exposures is no longer under the same radiological constraints as in the early phase.

(113) The Commission recommends that any new responder entering the site should be identified, trained, and equipped for the task assigned, and should formally give informed consent. Many of these responders are recruited for jobs which are not usually performed in the presence of radiation, such as civil engineering, and their stay in the damaged installation may represent a small part of their working lifetime. Their training should be adapted to the particular circumstances, and a special session may be organised by the operating management in order to overcome the lack of radiological protection knowledge and culture. As these responders work in difficult and stressful conditions, specific attention has to be devoted to ensuring that they have suitable working and housing conditions. The individual dose of responders should be monitored and recorded, and each responder should be informed about the exposure received.

(114) During the intermediate phase, the Commission recommends using a reference level of 100 mSv or below, and does not consider that the application of dose limits is appropriate. The reference level may be reduced during the intermediate phase depending on the progress of regaining control of the source and exposure situation at the installation. Medical care and subsequent health surveillance should be provided as necessary. Pregnant women and young persons aged under 18 years should not be involved in teams of responders on-site during the intermediate phase.

3.3.4. Protection of responders during the intermediate phase off-site

(115) Off-site, the intermediate phase starts when the source of the release has been stabilised, and finishes when the exposure situation for the population and affected areas is sufficiently well characterised to allow the authorities to decide the future of affected areas. The main tasks to be performed by responders are the characterisation of the radiological situation, the setting up of infrastructures for radiological control of foodstuffs and health surveillance of the population, and the decontamination of buildings and the environment. The individuals involved in these tasks are a mixed population of workers (occupationally exposed or not) and volunteers. The situation is still an emergency exposure situation, but the exposures of these responders can be relatively well controlled.

(116) The Commission recommends organising protection for off-site responders as much as possible during routine activities. The responders involved should be registered and informed about the necessary tasks where radiation is present, and any associated risks (right to know). Their dose should be assessed, and the information should be communicated to responders, and kept, as far as possible, on an individual basis. The Commission recommends using a reference level of 20 mSv per year or below to control individual exposures according to the circumstances. A

lower reference level is recommended for responders off-site during the intermediate phase compared with on-site because there should be no need for higher exposures in the conduct of their activities. The reference level may be reduced during this phase if the radiological conditions evolve favourably.

3.3.5. Management of responder exposures during the early and intermediate phases

(117) Some responders may be involved in both the early and intermediate phases. For these responders, the management of exposures should be guided by the objective to keep the total exposure during these phases to below 100 mSv. However, given the possibility of difficult and unpredictable intervention conditions on-site and even off-site, particularly during the early phase, it is important to bear in mind that a limited number of responders may receive exposures exceeding 100 mSv in total, or exceptionally in the range of a few hundred millisieverts. The Commission recommends that the exposures during the early phase should not necessarily restrict responders from involvement in the intermediate phase. It also recommends that appropriate and sustainable medical surveillance should be provided for responders with accumulated exposures higher than 100 mSv.

(118) When an occupationally exposed worker is involved as a responder, the exposure received during the response should be accounted for and recorded separately from exposures received during planned exposure situations, and not taken into account for compliance with occupational dose limits. Arrangements for dose records of responders based on agreement between the responsible authorities, operators, employers, and workers should be made in advance as part of the plan for nuclear installation accidents at the preparedness stage.

(119) The Commission recommends that occupationally exposed workers who wish to return to their regular activities and occupations when the intermediate phase is over should not be prohibited from doing so. The decision should be taken by the authority responsible for the installation on a case-by-case basis after a detailed review of the history of the exposures received before and during the response to the accident, as well as a thorough medical examination.

3.4. Protection of the public and the environment in the early and intermediate phases

(120) The protection of people in the early and intermediate phases relies on implementation of a set of protective actions that should be justified and optimised using reference levels. The goal is to maintain and/or reduce all exposures to as low as reasonably achievable given the societal, environmental, and economic factors shaping the lives of the individuals and communities residing and working in affected areas. The protective actions should be implemented using criteria based on reference levels to limit inequity in the distribution of individual exposure, with the particular aim of protecting vulnerable groups or particular communities such as indigenous populations.

(121) In *Publication 109* (ICRP, 2009a), the Commission recommended that a reference level for emergency exposure situations should typically be set in the band of 20–100 mSv, and that the selected reference level should be adapted to the potential or actual accident scenario. In these recommendations, there was no consideration about the possible duration of the emergency exposure situation beyond 1 year.

(122) In the current recommendations, the Commission specifies that during the early and intermediate phases, all reasonable protective actions should be taken to ensure that the most highly exposed individuals do not exceed 100 mSv for the entire duration of both phases. This is to mitigate acute exposures and to prevent deterministic effects. The Commission recognises that the duration of these phases may be less than or more than 1 year depending upon the circumstances. The Commission also recognises that, if possible, the most appropriate reference level during the early and intermediate phases may be lower than 20 mSv (see Table 6.1). It should be noted that in the case of a large possible intake of radioiodine, specific protective actions should be implemented.

(123) During the early phase, when the off-site radiological situation is still largely unknown and evolving rapidly, the reference level set during the preparedness plans for the corresponding scenario should inform the implementation of protective actions. This reference level may be used to establish operational criteria to be used as triggers for implementing particular protective actions (IAEA, 2011, 2015b). However, the situation may not develop as expected, and despite the protective actions taken, some exposures may be of the same order or even higher than the reference level. Conversely, all exposures may be lower than the reference level, particularly if the accident is less severe than the scenario planned in advance. Hence, it is important to characterise exposures as soon as possible, through modelling and undertaking initial measurements in the environment. This enables the authorities to adjust, if necessary, the extent of protective actions and/or the value of the reference level to optimise protection.

(124) During the intermediate phase, when the radiological situation is better characterised, it may be necessary to re-assess the reference level and to reduce it. For example, during the intermediate phase of the Chernobyl accident, the Soviet authorities reduced the reference level progressively (Kryuchkov et al., 2011).

(125) For protection of the environment, the Commission recognises that during the early phase, and possibly the intermediate phase, it may be difficult or impracticable to significantly reduce the concentrations or quantities of radioactive material deposited in the affected environment. In the early phase, the level of exposure of some animals and plants may be greater than the DCRLs. The framework recommended by ICRP to assess the potential impact on fauna and flora may be used to identify those species that may have been particularly affected, and to consider the need for further actions.

3.4.1. Protective actions for the early phase

3.4.1.1. Sheltering

(126) Some groups may require urgent protective actions to reduce their exposures in the event of an airborne radioactive plume passing above their homes. These groups, unless evacuated, should be recommended to shelter by remaining indoors, sealing windows and doors, shutting off ventilation systems if possible, and awaiting further instructions.

(127) Solidly constructed buildings can significantly reduce exposure to an airborne plume and attenuate radiation from radioactive material deposited on the ground. However, the sheltering of residents may not be sufficient to prevent potential serious health effects, and should be undertaken in conjunction with iodine thyroid blocking if possible.

(128) For certain facilities where evacuation may be difficult to implement rapidly in safe conditions (e.g. health facilities with elderly people or patients in a critical condition), sheltering may be the preferable action during the early phase. The staff that remain to take care of the sheltered people need to be trained and equipped as responders as part of emergency preparedness. These voluntary staff, who need to provide their informed consent at the end of their training, should be informed, in real-time if possible, of the evolution of the radiological situation, and equipped to take measurements and appropriate protective actions if necessary.

(129) Strict sheltering for periods of more than a few days may be difficult to maintain without significantly affecting the well-being of the sheltered population. Issues such as the need to receive medical attention or to obtain medical supplies, the need for farmers to look after their livestock, or simply the legitimate desire of families to be together may create delicate situations and generate stress. After a few days of strict sheltering, the evacuation of people should be considered if the likelihood of significant exposure persists. Evacuation should also be undertaken while the radioactive releases continue, and care should be taken to prevent external and internal exposures of evacuees as much as possible. This is a delicate operation that requires development of additional protective actions that should be identified in advance during the preparedness and planning stage.

(130) Due to the relatively short timescales involved, the lifting of sheltering is likely to be carried out without significant involvement of stakeholders, although a mechanism for communicating with those who are sheltered is essential. The withdrawal of sheltering means that either people are allowed to stay in their homes and return to their day-to-day activities with or without restrictions, or they are not allowed to stay and should be evacuated or relocated. However, before withdrawal of sheltering can happen, monitoring information is required to determine whether exposures from external irradiation, and inhalation of resuspended material from ground deposits, are likely to be of radiological concern once sheltering is lifted. The mobilisation and deployment of sampling and measurement teams take time, and it is essential to establish priorities considering the individual situations. If it is not

possible to be confident that the radiological situation supports the lifting of sheltering in a reasonable timeframe, consideration should be given to a well-planned evacuation of any group for whom continued sheltering may pose unacceptable or inadequately defined risks.

3.4.1.2. Evacuation and temporary relocation

(131) Evacuation represents the rapid, temporary removal of people from an off-site area to avoid or reduce short-term radiation exposures that could be sufficiently high to potentially result in severe tissue/organ damage (deterministic health effects) and increase the long-term risk of cancer and heritable diseases (stochastic health effects). It is most effective in terms of avoiding radiation exposure if it can be taken as a precautionary action before there is any significant release of radioactive material. However, evacuation may also be implemented after the occurrence of the releases or even at the time of the releases given the circumstances.

(132) Evacuation is a short-term protective action and its continuation may be necessary and justified in some cases if, for example, it is not possible to control the source of the release, if there is a significant risk of a further accident or release, or if high levels of radiation exposure persist in the environment. If the radiological conditions require people to stay away from their homes for a period longer than approximately 1 week, the initial evacuation may need to be followed by temporary or even permanent relocation.

(133) Past experience has revealed that evacuations are effective and occur frequently in response to emergencies involving natural and man-made hazards. However, evacuation can be detrimental for certain populations, such as patients in hospitals and nursing homes, as well as elderly people, if it is not well planned (Tanigawa et al., 2012).

(134) Experience has also indicated that voluntary evacuation may occur regardless of whether formal advice to evacuate has been given. Authorities should consider the negative and positive aspects of such self-initiated evacuation of people when carrying out preparedness plans for the early phase.

(135) Once people have been evacuated, decisions need to be made on whether and when they can return home or not, as evacuation centres are usually only equipped for short-term accommodation, such as in public buildings. These decisions are based both on the state of the radiological situation in the affected area, and the ability to provide decent living and working conditions for the population. The Commission recommends that the authorities in charge of the early phase, together with the evacuees and the authorities and professionals from the affected communities, should be closely involved in the complex decision-making process on returning or not to the evacuated area. This should be conducted in a transparent manner on the basis of all information available on the radiological situation, including the quality of the living and working conditions in the areas for which a return is envisaged.

(136) Characterising the radiological situation of the evacuation areas should be based on measurements of environmental contamination, as well as predictions on the evolution of the radiological situation and capability to improve it. The composition of the release, the complexity of the contamination pattern, and the size of the area affected determine how rapidly assessments can be made. Measurements should be taken for a variety of environments focusing on places where people spend their time, and an assessment made of future exposures to those who would be living in the affected area.

3.4.1.3. Iodine thyroid blocking

(137) Iodine thyroid blocking is based on the administration of a compound of stable iodine (usually potassium iodide) to prevent or reduce exposure to the thyroid due to inhalation and ingestion of radioactive iodine by saturating the thyroid with non-radioactive iodine. As stable iodine is only of benefit in protecting the thyroid against radioactive iodine, it should be accompanied by sheltering or evacuation. The effectiveness of stable iodine for thyroid blocking depends on its timely administration. Taking stable iodine shortly before or at the time of exposure to radioactive iodine offers the most effective protection. If stable iodine is administered too early or too late, the thyroid is less likely to be protected effectively. In the case of a prolonged release of radioactive iodine, a repeated intake of potassium iodine may be recommended (Benderitter et al., 2018). As the uptake of radioactive iodine may increase the risk of thyroid cancer, particularly at young ages, the administration of stable iodine during the early phase is particularly important for pregnant women and children (WHO, 2017).

(138) Due to the short time available, distribution of stable iodine may present a practical problem, especially if large population groups are concerned. Therefore, national authorities should give careful consideration to the most effective way to ensure the availability of stable iodine to potentially affected populations, including pre-distribution. At the dosage recommended by the World Health Organization, the overall benefits of thyroid blocking with potassium iodine during the early phase outweigh the risks of side effects in all age groups (WHO, 2017).

3.4.1.4. Decontamination of people

(139) Individual decontamination is the complete or partial removal of radioactive material from a person by a deliberate physical and chemical process. Urgent individual decontamination may be advised to reduce exposures to external radiation from contamination of clothes, hair, and skin, and to prevent inadvertent ingestion of such contamination. This measure may be particularly useful for protecting responders. It is unlikely that individual decontamination should be required outside the area in which evacuation has been advised. Evacuation of a group of people should not be delayed by action to decontaminate individuals.

3.4.1.5. Precautionary restrictions of foodstuffs

(140) Ingestion of contaminated food may be an important exposure pathway soon after the accident for people residing in affected areas. Consumers outside these areas may also be concerned that contaminated products are being placed on the market. Therefore, it is prudent to take actions as soon as possible in the early phase in affected or potentially affected areas in order to protect people and the image of the products. Protective actions at this stage mainly involve restricting the consumption of agricultural and fishery products, and drinking water, as well as bans on hunting and the gathering of wild foods. Monitoring of all food products from these areas may be necessary, and this may take a few days to a few weeks to be implemented. In the event of banning or restricting the consumption of foodstuffs, authorities should ensure the supply of non-contaminated food and water for people living or working in these areas.

(141) Monitoring of the radioactive contamination of milk, which is an important part of the diet of children in most countries, is particularly important during the early phase of an accident because it is a potential source of thyroid exposure from radioactive iodine. Where such restrictions are needed, the population should be instructed not to drink milk from cows or goats that have been grazing on contaminated pastures. In addition, the population should be instructed not to eat fresh vegetables, fruit, or other food that may have been subject to contamination during the radioactive releases.

3.4.2. Protective actions for the intermediate phase

3.4.2.1. Temporary relocation

(142) Temporary relocation involves the movement of people, either already evacuated or coming directly from their homes, to temporary accommodation that can meet all of their basic needs and where living conditions can be properly supported. Temporary relocation can last weeks, months, or several years depending on the characteristics and extent of the contamination, and it aims to avoid exposures considered too high or where essential food and water is significantly contaminated and cannot be replaced easily. The physical risks associated with temporary relocation are relatively small compared with those for evacuation, as the action can be implemented without haste and with enough time to interact with those involved. Temporary relocation is, however, associated with psychological effects (Oe et al., 2017; Ohto et al., 2017).

(143) The maximum period of time that temporary relocation can be tolerated depends on a range of social and economic factors. For example, there might be increasing discontent with temporary accommodation and living conditions, or simply the desire to establish settled social patterns back home. Conversely, there may be concerns about returning home, such as persistent residual exposures; lack of employment opportunities; need to repair or reconstruct abandoned houses; and insufficient infrastructure such as schools, hospitals, and shops.

3.4.2.2. *Foodstuff management*

(144) In the intermediate phase, radiological characterisation of food products, together with an understanding of the variation in radionuclide concentrations according to season, environmental characteristics, etc., enables a more detailed and adapted strategy for foodstuff management to be developed. This should take into account the radiological and non-radiological quality of the products, the restoration of consumers' confidence, and the possibility to maintain sustainable economic activities. For this purpose, it is necessary to consider the overall impacts of the protective actions on the local communities. Once the characterisation is sufficiently advanced for the authorities to have a relatively good understanding of the overall situation, the Commission recommends that radiological criteria for the consumption of products should be set, based on the reference level and expressed in measurable levels of radionuclides in foodstuffs (Bq kg^{-1} or Bq L^{-1}). The radiological monitoring of foodstuffs, based on these criteria, is key to facilitate trade inside and outside affected areas, while guaranteeing protection of the people.

(145) The Commission acknowledges that fixing such radiological criteria is complex and needs to balance many considerations, taking into account the interests of producers, retailers, and consumers at local, national, and international levels. The Commission recommends that relevant stakeholders should be involved in the decision-making process (Kai, 2015). In-depth debate at national level is needed to maintain a degree of solidarity in the country.

(146) Guideline levels have been developed by the Codex Alimentarius Commission for International Trade (FAO/WHO Codex Alimentarious Commission, 2006). These levels are based on a dose criterion of 1 mSv per year assuming that a maximum of 10% of the diet consists of contaminated food. This assumption may not be valid and another percentage might be more adapted for some local communities. Hence, the radiological criteria for foodstuffs may be set below the Codex guideline levels. Conversely, if the contaminated food affects a smaller part of the diet, the radiological criteria may be set to higher values. Higher radiological 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. Such decisions must be taken in close co-operation between authorities, experts, local professionals, and the affected communities, as was the case in Norway with reindeer meat produced by the Sami population after the Chernobyl accident (Skuterud et al., 2005). Consequently, the radiological criteria for foodstuffs set for managing the local situation may be specific and different from those adopted for international trade. Radiological criteria for managing the local situation may evolve as an incentive to further improve the radiological quality of foodstuffs.

(147) In the intermediate phase, the radioactive contamination of foodstuffs can be improved by many protective actions that aim to reduce the transfer of radionuclides in the food chain from production to consumption (Nisbet et al., 2015). These actions include, for example, removal of topsoil, ploughing and chemical

treatment of soils, provision of clean feed or feed additives to livestock, and industrial-scale food processing to remove contamination. The actions selected depend on the physical and chemical properties of the radionuclides released, season of the year, and the types of soil and land use (Bogdevitch, 2012).

(148) In addition to foodstuff management, water supply should be monitored regularly during the intermediate phase to verify that there is no progressive accumulation of contamination following run-off in affected areas.

3.4.2.3. Management of other commodities

(149) Commodities other than foodstuffs may also be contaminated following a nuclear accident. All products stored outside can be contaminated, including vehicles, packaging, and transport containers. This is also the case for raw materials such as wood, and ores from quarries. Although the contamination of commodities may not be a significant contribution to exposures, it is viewed as a significant concern by stakeholders, and the commodities may need to be managed. The type of management depends on the level of contamination, type and number of commodities, and circumstances of use. Moreover, it is sometimes necessary to implement a validation process of the radiological quality of potentially contaminated commodities.

3.4.2.4. Decontamination of the environment

(150) In the intermediate phase, the removal of contamination from surfaces and soils can be a very effective action to reduce exposure. There are many techniques that can be applied to decontaminate buildings and road surfaces, soils, and vegetation (Nisbet et al., 2015). However, decontamination of the environment has the potential to lead to the production of contaminated waste, often in large quantities. Appropriate characterisation, segregation, temporary storage (potentially long term), and disposal routes are needed for contaminated waste. Such removal of contamination also poses the potential for significant damage to the environment itself.

(151) The decontamination of buildings (public and private), roads and paved areas, open spaces, recreational areas, and agricultural land starts during the intermediate phase and, depending on the size of the areas affected, may continue into the long-term phase. Priority should be given to places where people spend most of their time and places which are contributing the most to their exposure. Realistic exposure assessment adapted to the local conditions may help to identify the major contributions to individual exposures. For these decontamination actions, the Commission recommends applying the principle of optimisation using a reference level with a view to effectively reduce individual exposures. This should be done in close consultation with the affected population, considering the actual characteristics of the

exposure situation as well as the associated societal, environmental, and economic factors, to ensure that negative consequences do not outweigh the intended benefits.

3.4.2.5. Management of business activities

(152) The economic activities of various companies may be affected by a nuclear accident (see Section 2.2.4). During the intermediate phase, companies located in the affected areas may need to establish protective actions for their employees, taking into account the concerns and expectations of their families. They may also need to set up dedicated actions to preserve their business, such as radiological monitoring of their products, and actions to preserve their image. Certain companies may be led to relocate.

(153) The first step for companies relies on characterisation of the radiological situation. Taking into account the fact that most companies are not familiar with radiological protection issues, the support of experts and the provision of adequate guidelines, including specific radiological criteria, are necessary. The aim of the characterisation is to identify who is exposed and what is contaminated, where, when, and how.

(154) Depending on the level of contamination, some companies and economic activities could be maintained in affected areas, with or without specific decontamination actions. In any case, employers would have to ensure an adequate working environment for their staff and production, and take account of the possible evolution of contamination.

(155) Exposure at work in economic activities maintained in the affected areas results from residual contamination of the environment and not from the activities themselves, except in special cases where the nature of the work leads to significantly higher exposure to this residual contamination. Therefore, the Commission recommends that the concerned workers should be protected as members of the public. However, it is the responsibility of their employer to ensure their protection, notably by providing them with appropriate information on radiation risks, helping them to implement a monitoring programme for themselves if they wish and possibly for their families, and considering how they might reduce their exposures by implementing self-protective actions. For workers involved in activities involving specific exposure situations, such as foresters and employees of sawmills in forest regions, the Commission recommends that they should be considered as occupationally exposed.

(156) A large number of industries are also challenged by the presence of radioactivity actually or potentially affecting their products. Some of them would have to demonstrate the radiological quality of these products, notably for export. For other industries for which the products or the activities themselves could be affected (e.g. quarries, forest activities, tourism), a decision would need to be made about whether or not to maintain the economic activity.

(157) For economic activities in affected areas, there is a need to develop a radiological protection culture and ensure that mechanisms are put in place to establish

dialogue with different stakeholders to help workers, their families, and consumers to make informed decisions to protect themselves.

3.4.3. The co-expertise process

(158) The Commission recommends adopting the co-expertise process during the intermediate phase. This process of co-operation between experts, professionals, and local stakeholders aims to share local knowledge and scientific expertise for the purpose of assessing and better understanding the radiological situation, developing protective actions to protect people and the environment, and improving living and working conditions. The co-expertise process is an integral part of the practical implementation of the optimisation principle based on the involvement and empowerment of stakeholders. It contributes to the development of self-help mechanisms implemented by affected populations complementing protective actions driven by responsible organisations at national and local levels (ICRP, 2009b, 2016). Experiences from the Chernobyl and Fukushima accidents have demonstrated the effectiveness of this process (Liland and Skuterud, 2013; Lochard, 2013; Ando, 2018; Takamura et al., 2018; Yasutaka et al., 2020).

(159) From an ethical point of view, the co-expertise process focuses on the restoration and preservation of human dignity, which is one of the core values of the system of radiological protection (ICRP, 2018). More particularly, the process can be seen as reflecting inclusiveness, which is the procedural value behind the concept of stakeholder involvement. Beyond that, it allows the implementation of empathy (i.e. it provides the experts with opportunities to immerse themselves in and to reflect upon the experiences, perspectives, and contexts of others), which in turn helps find suitable and sustainable protective actions.

(160) The co-expertise process takes time, requires dedicated resources for local and individual radiological monitoring, and can only be envisaged with the support of radiological protection experts or professionals who are committed to working with the population for a long period (Gariel et al., 2018; Schneider et al., 2019). The co-expertise process is a step-by-step approach favouring the development of a radiological protection culture among all involved stakeholders (see Fig. 3.1).

3.4.3.1. Steps of the co-expertise process

(a) Establishing dialogues

(161) The first step is to engage in a dialogue with a group of people from a community affected by the accident to share experience and knowledge. Within this dialogue, affected people bring their knowledge about their living conditions and that of their communities, while experts bring their knowledge about the science of radiation and their experience on the practical implementation of radiological protection. Experts and affected people also share their perception of the situation

Fig. 3.1. The co-expertise process.

and its consequences for daily life, including questions, concerns, and expectations. In a context of lack of knowledge about radiological issues among the population and distrust vis-à-vis experts and authorities, a real challenge for everyone is to keep an open mind and maintain mutual respect.

(b) Joint characterisation of the radiological situation

(162) The second step aims at involving people in measurements to make the radioactivity 'visible' in order to raise awareness of when, where, and how they are exposed in their daily life. For this purpose, an inclusive monitoring approach should be developed based on measurements performed by the authorities and/or by affected people (self-monitoring). Measurements have to be made step-by-step, starting from the source of exposure and extending gradually to include the exposures received by people, through various exposure pathways, so that the exposure situation of individuals and the community is better characterised. Experience has shown that sharing results of measurements for the purpose of discussing and comparing individual situations is a powerful means for identifying opportunities to improve the radiological protection of the affected people. This joint characterisation allows for a better understanding of the local situation, and puts it into perspective, taking into account radiological criteria and comparison with other situations of radiological exposure.

(c) Identifying and implementing protective actions

(163) The third step aims at both local people and experts to identify possible protective actions appropriate to the local situation to reduce avoidable individual exposures. It allows for the identification of self-help protective actions that can be implemented by affected individuals, as well as enabling an assessment of protective

actions driven by the authorities with possibilities to adapt them if necessary. The experience gained through this process may also be conducive to reviewing the corresponding radiological criteria. The co-expertise process allows local stakeholders to make informed decisions for their own protection. Implementing protective actions inevitably requires technical, human, and financial resources, and calls for support from experts and authorities.

(d) Organising citizen vigilance and implementing local projects

(164) The fourth step in the co-expertise process aims to organise a radiological monitoring programme within the community to ensure ‘citizen vigilance’ regarding the radiological situation, as well as to identify and implement local projects at the level of affected communities. These projects, which may be of very diverse nature (educational, social, memorial, cultural, environmental, economic, etc.), should consider radiological and non-radiological factors, and should be implemented with the aim of improving the protection of people and the environment, as well as the well-being of people and the quality of community life. The involvement of local populations in these projects, with the support of authorities, experts, and local professionals, is a determining factor in their effectiveness and sustainability. For the implementation of local projects, appropriate governance structures involving stakeholders should be established to ensure legitimacy, transparency, and fairness of the decision-making process.

3.4.3.2. Radiological protection culture

(165) The co-expertise process is effective in empowering individuals and communities affected by radiation to know how to protect themselves, and thus to develop a practical radiological protection culture needed to face the consequences of the nuclear accident. The Commission defines this culture as the knowledge and skills enabling citizens to make well-informed choices and behave wisely in situations involving potential or actual exposures to ionising radiation (ICRP, 2018).

(166) This culture should be practical in order to help people to address concerns in their daily life. It allows them to:

- interpret the results of measurements (e.g. ambient dose rates, internal and external doses, contamination of foodstuffs);
- cope with the presence of radioactivity in everyday life by understanding where, when, and how they are exposed;
- build their own benchmarks about the level of radioactivity they are confronted with;
- collect relevant information to make informed decisions about their protection and to take actions (self-help protection); and

- judge the appropriateness and effectiveness of the protective actions they implement themselves and those implemented by the authorities.

(167) The development of the practical radiological protection culture is based on a learning process that connects scientific knowledge underpinning radiological protection with the actions of daily life. It enables people to restore their autonomy regarding decisions that affect them, which has been seriously impaired at the time of the accident. Furthermore, it contributes to reconnecting people, helps to develop their solidarity, and provides an opportunity for them to look to the future with more confidence.

3.5. Moving from the intermediate phase to the long-term phase

(168) Protective actions implemented during the early and intermediate phases should be lifted, adapted, or complemented when authorities and stakeholders consider that these actions have achieved their expected effect, or when their continued application is no longer justified (i.e. cause more harm than good in the broadest sense). However, experience shows that, in practice, the lifting of protective actions implemented during the early and intermediate phases is a difficult decision. This requires that the actions are considered no longer necessary and that this evaluation is shared. The lifting of an action often implies the implementation of other replacement or complementary actions more suited to the situation. In practice, this move needs the co-ordination and support of various organisations involved in the management of the situation. It also requires effective mechanisms to properly inform and involve the various stakeholders.

(169) If the level of residual contamination in affected areas is such that sustainable health, societal, economic, and environmental conditions cannot be achieved through protective actions, the authorities may not allow populations, previously subject to evacuation or temporary relocation, to return to their homes. The decision to prohibit return to these affected areas should be justified with due recognition of the severity, and the irreversible nature for some people, of such a difficult decision. For affected areas with a lower level of contamination, the authorities may decide to allow people to stay or return to their homes and to live there permanently, considering the expected levels of exposure and the ability to recover sustainable and suitable living and working conditions in a reasonable timeframe. Such decisions should be duly justified based on all the information available concerning the radiological situation, and the state of infrastructure and services in these areas.

(170) In practice, allowing people to return home and to live there permanently requires an assessment of their future exposures and the associated risks. This assessment should be based on measurements of ambient dose rates and environmental and foodstuff contamination, predictions on the evolution of individual exposures, and capability to improve the radiological situation. Environmental and food monitoring data coupled with realistic modelling can be used to predict future exposure (Takahara et al., 2020).

(171) Decisions on allowing those who have been temporarily relocated to return to their homes involve an extensive dialogue with the affected people and the

authorities and professionals in their communities. It is important to provide inhabitants with full details about the living and working conditions, and the quality of the environment they will face if they choose to return to their homes. They are entitled to expect the support of experts in co-expertise processes, and also access to appropriate medical services and education (Miyazaki, 2017).

(172) The Commission emphasises that individuals have a basic right to decide about their future. All individual decisions about whether to remain in or leave an affected area, or to return home or not, including those of voluntary evacuees, should be respected as a matter of dignity, and supported by the authorities. Strategies should also be developed for relocation of those who either do not want or are not permitted to move back to their homes.

(173) Removing people permanently from an area and forbidding its use (at least for the foreseeable future) is a difficult decision to take. Radiological considerations may be used to delineate the boundary of such areas, although existing geographic or jurisdictional boundaries may also be considered for social reasons.

(174) The decision to allow evacuated people to return may be accompanied by the authorities setting a radiological criterion above which it is mandatory to relocate the population permanently, and below which inhabitants are allowed to stay subject to the implementation of protective actions to maintain and possibly improve the radiological situation resulting from the early and intermediate phases. The Commission does not recommend any specific value for such radiological criteria. If any is selected, it should be consistent with the guidance concerning the management of existing exposure situations (see Section 4). To ensure consistency, the selection of a radiological protection criterion to allow people to live in affected areas should be discussed and decided together with the selection of the value of the reference level to be applied in the long-term phase.

(175) The Commission recommends that the decision by the authorities to allow people to live permanently in affected areas should be taken in close consultation with representatives of the local communities and all other stakeholders when the following conditions and means, at least, are met:

- characterisation of the radiological situation of the environment, foodstuffs, goods, and people in affected areas is sufficiently well achieved to allow effective decisions to be taken to protect people and the environment, and to improve living and working conditions;
- mechanisms are established for the involvement of local stakeholders in decision-making processes. These mechanisms should be transparent and understood by all relevant stakeholders;
- a system for radiological monitoring of the environment and measurement of individual external and internal doses has been established, as well as a health surveillance system, including appropriate mechanisms for collecting, storing, and using data; and
- appropriate mechanisms (e.g. co-expertise process) have been put in place to involve affected people in improving their well-being and the quality of life in their communities with the support of local authorities and professionals.

4. THE LONG-TERM PHASE

4.1. Characteristics of the long-term phase

(176) The long-term phase begins on-site when the authorities in charge of managing the accident consider that the damaged facility is secured. Off-site, the long-term phase begins when the authorities have made their decisions concerning the future of affected areas, and have decided to allow residents, who wish to do so, to stay permanently in these areas. These decisions mark the beginning of the long-term phase, which the Commission regards as an existing exposure situation, to be managed with application of the principles of justification of decisions and optimisation of protective actions with reference levels.

(177) Experiences from the Chernobyl and Fukushima accidents have shown that beyond the consideration of radiological aspects, the rehabilitation of living and working conditions after a large nuclear accident is a complex process in which all dimensions of individual and community life are involved and interconnected. These two extremely socially disruptive accidents demonstrated that management of the long-term phase based solely on radiological principles and criteria was not sufficient to respond to the challenges faced by individuals and communities in affected areas. Such management is inadequate for rehabilitating the living conditions of the inhabitants, and experience has shown that it also causes unnecessary divisions that can affect individual well-being and the quality of life of affected communities (Ando, 2016). Thus, while radiological principles and criteria are an essential input to the management of the long-term phase, they should be used appropriately and with due flexibility for accompanying the rehabilitation of the living and working conditions of affected individuals and communities.

(178) As in many existing exposure situations, the level of exposures of people residing in affected areas is largely driven by their individual behaviours, which generally results in a very heterogeneous distribution of individual exposures. The range of exposures may be affected by many factors including:

- location of home and work with respect to contaminated areas;
- profession or occupation, and therefore time spent working in particular areas affected by contamination; and
- individual habits, particularly diet, which could be significantly dependent on the socio-economic situation.

(179) Experience has shown that large differences in levels of exposure may exist between neighbouring communities; within families in the same community; or even within the same family according to diet, lifestyle, and occupation. These differences generally result in a skewed dose distribution where a few individuals receive a larger exposure than the average.

(180) People residing and working in affected areas, even temporarily, should be duly informed about the radiological situation. They should receive support from

authorities and experts, not only to ensure adequate protection against the radiation, but also to guarantee sustainable living and working conditions, including respectable lifestyles and livelihoods.

(181) It is the government's responsibility to provide relevant guidance to the population on how to protect themselves, and the conditions, means, and resources for implementing this protection effectively. Hence, the government, or the responsible authority, together with the stakeholders, should regularly evaluate the effectiveness of the protective actions in place, including self-help protective actions carried out at community or individual levels, in order to provide adequate support on how to ensure long-term protection and to further improve the situation.

4.2. Radiological characterisation

4.2.1. Exposure pathways

(182) In the long-term phase, exposure pathways reflect the level and extent of the initial deposition of radioactivity, the results of actions implemented to decontaminate the environment, and radioactive decay. The importance of different exposure pathways depends on the type of radioactive material that has been dispersed and deposited. Rainfall and weathering may have influenced the penetration of deposited radionuclides into soil and some migration via water pathways or through resuspension. Certain areas, such as alpine pastures, forests, and upland areas, may show longer retention in soils than agricultural areas. The absorption of contamination in plants depends on the species. High levels of transfer to particular foods (e.g. berries and mushrooms in forests) may give rise to elevated intakes. Contamination of livestock depends on their diet; this can be controlled, unlike that of fish and wild animals. The transfer to animals depends on their intake and metabolism of the various radionuclides.

(183) In the longer term, one or a few radionuclides become the principal contributors to individual exposure. External exposure due to deposited radionuclides depends on the ambient dose rates and the time spent by individuals at various locations such as at home, work, and for recreation. Internal exposure arises from intake via consumption or inhalation of contaminated material. Radionuclide intake by humans may arise from consumption of vegetables, milk, meat, and fish. There may be considerable variation in intakes by the population over time, depending on the season of the year and resulting agricultural practices, the types of soil and vegetation, and individual diets.

4.2.2. Radiation monitoring

(184) At the beginning of the long-term phase, radiological characterisation of the affected areas should have been carried out, providing a good understanding of the spatial distribution of the contamination. In affected areas where people are allowed

to live, it is important to follow the evolution of the radiological situation in order to adapt protective actions if necessary. This is done through maintaining and, if necessary, adapting the monitoring programme of external and internal exposure of individuals carried out by the authorities as well as individuals and communities.

(185) This programme not only provides data on the evolution of contamination in affected areas, but also helps to control the concentration of radionuclides in foodstuffs. It provides information on external ambient dose rates by using devices displaying the results in different places. It allows each individual to have access to his/her exposure, and also to know where, when, and how they are exposed. This information is essential for implementation of the co-expertise process. In practice, this should provide affected communities with the means (measuring equipment and qualified personnel) to measure ambient exposure levels, individual external exposures, concentrations of radionuclides in foodstuffs and the environment, and individual internal exposures. It is also important to provide support for understanding and interpreting the data provided by this monitoring. Environmental monitoring of fauna and flora should also be considered.

(186) The effectiveness of the monitoring programme relies on its ability to cope with the specificities of the local affected areas, which is particularly important for determining potential groups at risk. The sustainability of such a programme requires continual maintenance and training to be supplied by national and local authorities.

(187) Experience shows that the diversity of organisations involved in implementing the radiation monitoring programme (authorities, expert bodies, local and national laboratories, non-governmental organisations, private institutes, universities, local stakeholders, nuclear operators, etc.) is an important factor in consolidating the assessment of the radiological situation. It also contributes to improving confidence of the affected population in the measurements.

4.3. Protection of responders during the long-term phase

(188) In the long-term phase, the aim on-site is to dismantle the damaged installation, including management of the corresponding waste. The exposure situation is mainly characterised and the source is mostly under control, although some technical difficulties may remain and unforeseen situations may occur at any time. For the management of responders on-site, the Commission recommends setting a reference level of 20 mSv per year or below, and applying the requisites for occupational exposure, as relevant. The Commission recognises that some authorities and stakeholders may wish to apply dose limits. This may be suitable, but not essential, in circumstances when the source is well characterised and controlled. Many responders are recruited for jobs which are not usually performed in the presence of radiation, such as civil engineering works; therefore, their training should not only include basic information on radiation risk and radiological protection principles, but also on the particular working conditions in which they will have to work. Circumstances on-site

may require planning for exposures higher than the reference level. In that case, the Commission recommends special arrangements limited in time, which should be prepared with the greatest care after deliberation between concerned parties with the aim of optimising the protection.

(189) Off-site, the tasks to be undertaken by responders during the long-term phase aim to continue and complete the cleaning and decontamination of buildings and the environment initiated during the early and intermediate phases. Responders are also involved in supporting the implementation of long-term protective actions to maintain and/or reduce exposures, and to improve the living conditions of people residing and working in affected areas. Responders off-site are not expected to be confronted with situations leading to high exposures. As for the intermediate phase, many groups of people may be involved in the implementation of protective actions, including the residents themselves. The exposure of these residents should be considered as public exposure, and should be managed using the same requisites as for the general population in affected areas.

(190) For responders involved in cleaning or decontamination operations, and the implementation of protective actions in the long-term phase, the Commission recommends an approach commensurate with the level of exposure and adapted to the circumstances. When protective actions are implemented in a restricted area not open to the public, it is recommended to manage protection using a reference level of 20 mSv per year or below. However, when protective actions are implemented in public areas, the Commission recommends that the reference level should be within the lower half of the 1–20 mSv per year band.

4.4. Protection of the public and the environment in the long-term phase

(191) Management of the long-term phase relies on implementing a set of protective actions that continue and complement actions implemented during the early and intermediate phases. For the protection of people, the goal is to optimise protection (i.e. to maintain and/or to reduce all exposures to as low as reasonably achievable, and to restrain inequities in the distribution of individual exposures). This should be done taking into account the societal, environmental, and economic factors shaping the lives of the individuals and communities residing and working in the affected areas. The protective actions include those implemented by the authorities at national and local levels, and self-help protective actions implemented by the affected population within the framework provided by the authorities to support the co-expertise process (see Section 3.4.3).

(192) In *Publication 111* (ICRP, 2009b), the Commission recommended 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 per year band depending on the circumstances, with further mention that a typical value in a long-term post-accident situation is 1 mSv per year. This coincides with the ‘desire from the

exposed individuals, as well as from the authorities, to reduce exposure levels so that they are in the range of those in situations considered as 'normal'' (ICRP, 2007).

(193) The Commission now recommends that optimisation should be implemented in the long-term phase using a reference level selected in the lower half of the 1–20 mSv per year band with the objective to reduce exposure progressively to the lower end of the band, or below if possible. The selection of the reference level should take into account the actual distribution of exposures in the population and the priorities for their reduction. As mentioned in *Publication 111* (ICRP, 2009b), the Commission also reiterates that the process for selecting the reference level should result from a careful balance of many inter-related factors, including the sustainability of social life and economic activities, as well as the quality of the environment, and should appropriately reflect the views of all relevant stakeholders.

(194) The Commission recommends that some types of protective actions should be maintained during the long-term phase if a large proportion of the affected population receive exposures above the reference level. Depending on the accident scenario, this could take several years, or even decades, because exposure of people living and working in contaminated areas largely depends on their habits and living conditions, which cannot be strictly controlled. It is therefore not possible to guarantee that all individual doses will be kept below the reference level in the long term. Past experience referred to in *Publication 111* (ICRP, 2009b) shows that after a few years, the combined effect of weathering, radioactive decay, and the implementation of appropriate protective actions results in exposure below 1 mSv per year for the large majority of the people who live and work in areas where they are authorised to reside. Only a very small proportion of the population is likely to receive exposures above a few millisieverts per year.

(195) In order to be effective, the reference level for protection of the public that is selected at the end of the intermediate phase, when the authorities take their decision on the future of the affected areas, should reflect the radiological situation correctly. This is based on the characterisation process, taking into consideration the relevant societal, environmental, and economic factors. As a reference level is meant to help guide optimisation efforts, selecting a value that is too high can be of little incentive to engage authorities and other stakeholders in the rehabilitation of their living conditions and those of their communities. Similarly, selecting a value that is too low can impact on the societal conditions and impair economic activities of the areas, and be counterproductive. Selection of the reference level to manage the long-term phase is a complex decision that should be informed by societal and ethical value judgements (ARPANSA, 2017). Due to this complexity, the Commission recommends that stakeholders who will be confronted with the situation should be involved as much as possible when selecting the value of the reference level.

(196) For the protection of non-human biota, the objective is to reduce exposures to as low as reasonably achievable, compatible with the protective actions adopted for people, with the aim to preserve biodiversity and the reproduction of species. In areas significantly impacted by the accident, and in places where highly contaminated materials have been disposed or stored, a specific characterisation to protect non-human

biota should be performed using the framework recommended by the Commission (ICRP, 2014) (see Section 2.3.3). The impact on non-human biota should be taken into account in the justification of decisions and optimisation of protection.

(197) The management of the long-term phase relies on the implementation of a rehabilitation programme coping with numerous dimensions (social, economic, health, environmental, etc.) according to the level of contamination and its space and time distribution. This programme should include a protection strategy combining a set of dedicated protective actions addressing the specific challenges of the exposure situation for the affected communities. It should also include health surveillance to follow the health status of the affected population as well as accompanying measures, notably to support the development of citizen initiatives and local projects, as well as the dissemination and transmission of the gained experience in managing the situation.

4.4.1. Protective actions for the long-term phase

(198) The protective actions available for the long-term phase are many and varied, ranging from removing the contamination present in the environment (decontamination and waste management) to implementing collective and self-help protective actions to control external and internal exposures (management of food products, dietary advice). They may be used in isolation or in combination as part of a broader protection strategy, such as in the agricultural domain (Bogdevich, 2012). Some actions with a generic character, such as clean feeding of livestock, may be applied identically and systematically throughout affected areas, whilst other actions, such as soil ameliorants, may only be applicable to particular locations based on the exposure conditions. For example, a protective action may only be effective for one type of land use or soil. Other options may generate large amounts of waste or may only be effective at certain times of the year or under particular conditions. The evaluation, selection, and combination of protective actions should be based on a realistic assessment of their potential impacts as well as on the input from a wide range of stakeholders. Their implementation is a dynamic process, which changes with the evolution of the radiological situation.

(199) Self-help protective actions are key for the sustainability of protection, and the dissemination of the practical radiological protection culture in the affected areas and its transmission to future generations. Experience has shown that maintaining citizens' vigilance is a challenge. To be successful, authorities should provide technical guidance and on-going support for development of the co-expertise process and implementation of self-help protective actions.

4.4.1.1. Decontamination and waste management

(200) The decontamination of buildings and public places (e.g. schools) and the environment near to dwellings starts in the intermediate phase, and may continue for

some time (several years) during the long-term phase. The Commission recommends that decontamination actions should be carried out in close consultation with the residents and users of dwellings, buildings, gardens, and public and recreational areas to identify the areas that either contribute significantly to exposures or are of primary concern for these people.

(201) Decontamination actions notably contribute to reducing external exposure (Tsubokura et al., 2019). In practice, empowerment of people through their involvement in co-expertise processes allows them to better manage their own external exposure by compiling local maps of dose rates at places where they live, work, and relax. In doing so, they can then identify places where the higher ambient dose rates are recorded, 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.

(202) The issue of waste should be considered when making decisions on which decontamination actions to adopt. Most of the waste in the affected areas comes from materials derived from the cleaning and decontamination of buildings, roads and paved areas, soil and vegetation, contaminated agricultural products, other domestic and commercial refuse, and waste treatment (e.g. ashes after incineration, sludge from water treatment). The activity concentration may be low, moderate, or high depending on the initial level of contamination and the type of treatment.

(203) The generation of radioactive waste during decontamination should be considered carefully, taking into account the available disposal routes and possible alternatives. In the long-term phase, radioactive waste should be managed with the aim of finding sustainable options. Experience shows that after a large nuclear accident, the principles and options usually used for the management of radioactive waste for normal operations need to be adapted given the large quantities, the radiological characteristics, and the nature of the waste generated by the decontamination processes. Specific waste management options, based on the principles of justification and optimisation, should be implemented, considering the context (i.e. type and severity of the accident), extent of contamination, type and volume of waste generated, radiation exposure of those involved in waste management, etc. Radiological protection aspects, as well as societal, environmental, and economic considerations that characterise the situation after an accident, should be taken into account.

(204) For the management of radioactive waste generated by decontamination actions, the Commission recommends that the reference levels set for public or environmental exposure should be taken into account, considering exposures from radioactive waste as one of the sources of exposures. Relevant stakeholders should be involved as much as possible in decisions related to the management of decontamination waste (particularly storage locations) and selection of the associated protective actions (particularly surveillance of sites, as well as potential re-use and recycling).

(205) The Commission recommends that surveillance of waste storage and disposal sites should be carried out for as long as necessary. Experience shows that

involving local residents in the surveillance of decontamination waste is an effective approach to ensure the sustainability of these storage and disposal sites.

4.4.1.2. Agriculture, fisheries, and foodstuff management

(206) During the long-term phase, the possible persistent migration of contamination in soil means that agricultural protective actions are still relevant (see Section 3.4.2.2). Maintaining long-term restrictions on the production and consumption of foodstuffs may affect the sustainability of affected areas. Whenever possible, protective actions should be implemented to maintain local production. However, there may be situations where farmers need to consider changing the type of agricultural production carried out to remain economically viable (e.g. feed production instead of food, crops that concentrate less radioactivity, seed production, non-food products). They may even need to consider a change of land use to non-agricultural activities.

(207) The Fukushima accident highlighted the significant contamination of the marine environment and its consequences on fishing activities. It is not possible to control contamination levels in marine fish. These depend on the species and the location of fishing grounds. Adequate monitoring makes it possible to manage fishing activities according to these two parameters. It is also possible to mainly use the fishing resources in processing instead of direct sales. In both the Chernobyl and Fukushima accidents, freshwater fish also became contaminated due to direct deposition of radioactivity in lakes and rivers, and run-off from contaminated soil.

(208) The monitoring of ingestion pathways is an important component of the protection of the public. Experience shows that maintaining radiological monitoring of foodstuffs in the long-term phase is useful to gradually restore the confidence of food distributors, retailers, and consumers inside and outside the affected areas (Strand et al., 1992; Skuterud and Thorring, 2012). In addition, the co-expertise process with the provision of monitoring devices to local communities for individuals to monitor radiation levels in local agricultural produce, food from private gardens, and food gathered from the wild (e.g. forest mushrooms, vegetables, wild game, freshwater fish, etc.) should contribute to the implementation of self-help protective actions.

(209) In practice, local people can act according to the radiological quality of the foodstuffs consumed each day. This assumes that they have access to the measurements of local products, including those from their private gardens. Based on the results of these measurements, they can identify products that are usually more contaminated than others (e.g. mushrooms are more readily contaminated than vegetables and fruits). In this context, they can adapt their dietary habits to reduce the ingested fraction of contaminated foodstuffs. Whole-body measurements can help the affected people to evaluate the efficacy of changes in their diet.

(210) It is the consumer who ultimately decides whether or not to buy food products from contaminated areas. This has a significant impact on the market. In developing a sustainable strategy for food production and fishing activities, it is important to ensure product quality (radiological and non-radiological) and to

restore consumer confidence. The Commission recommends that relevant stakeholders (authorities, farmers' and fishermens' unions, food industry and food distributors, retailers, consumer associations, etc.) and representatives of the general population should be involved in the decision-making processes related to maintaining and adapting agricultural production and fisheries, taking into account the expectations of consumers on the quality of foodstuffs. Thorough dialogue at regional and national levels is necessary to achieve a certain degree of solidarity within the country.

4.4.1.3. Economic and business activities

(211) During the long-term phase, the evolution and sustainability of economic activities require that the radiological monitoring of employees, the working environment, and products should be maintained and adapted according to the residual contamination and the expectations of the different stakeholders. This monitoring should contribute to the long-term vigilance, thus enabling additional or modified protective actions to be identified, as necessary.

(212) Some companies that were evacuated or relocated during the early or intermediate phases may wish to consider resuming their operations in affected areas, and new companies may consider starting economic activities in these areas. Depending on the activities of these companies, a dedicated monitoring programme, as mentioned above, could be implemented. It is also essential to provide the means for maintaining and further developing a radiological protection culture for employees who are also consumers.

(213) As mentioned in Section 3.4.2.5, the Commission recommends that people employed for various economic activities in affected areas should be treated as members of the public.

4.4.2. Health surveillance

(214) Whatever the level of exposures in affected areas, experience shows that the presence of contamination and its potential health impacts remain a widespread concern among the population in the long-term phase. It is essential to respond to this concern by continuing and adapting the health surveillance implemented in the previous phases. This should be done with consideration of prudence with regard to the effects of radiation and respect for the autonomy of affected people (Oughton et al., 2018).

(215) Health surveillance in the long-term phase should be composed of three main components (Oughton et al., 2018; WHO, 2006):

- the medical follow-up of people – expected to be few – who have received exposures during the early and intermediate phases that have resulted in clinically severe tissue or organ damage (e.g. skin burns, cataracts, etc.) or sufficiently high levels of exposure to justify preventive surveillance;

- health monitoring of the general population for potential adverse effects (incidence of radiation-induced cancers as well as health consequences due to changes in lifestyle) and psychological consequences of the accident. A subcategory of health monitoring is the follow-up of potentially vulnerable groups (e.g. young children, pregnant women); and
- specific epidemiological studies to provide information on the possible radiation health effects in the long term for the exposed population.

(216) For the first component, besides the necessary medical treatment, regular medical check-ups should be established, and particular attention should be devoted to the evolution of their general health status.

(217) For the second component, a dedicated health monitoring programme of the exposed population should be developed, including an initial medical evaluation, dose assessment, medical treatments as required, follow-up of health status, and enquiries on social and psychological conditions of the population and development of adequate support. The main goal of this programme is to characterise and improve the health and living conditions of affected populations. Its implementation requires the development of health surveys, health databases, and mechanisms for providing information and access to health support.

(218) As an increased radiation-induced risk of the incidence of thyroid cancer was observed among exposed children after the Chernobyl accident (UNSCEAR, 2018), specific monitoring programmes for the thyroid may be useful to detect severe thyroid disorders as early as possible. However, such monitoring should be organised ensuring that benefit outweighs harm at the population level (Togawa et al., 2018). Systematic screening can lead to overdiagnosis of thyroid cancer (Katanoda et al., 2016; Ohtsuru et al., 2019) and adverse psychological issues (Midorikawa et al., 2017, 2019; Midorikawa and Ohtsuru, 2020). In this regard, a long-term thyroid health monitoring programme should be mainly conducted for those individuals exposed in utero or during childhood or adolescence who received an absorbed dose to the thyroid in the range of 100–500 mGy or more (IARC, 2018).

(219) Concerning the third component of health surveillance, the development of epidemiological studies should be considered with due regard to addressing the concerns of the affected population (WHO, 2006).

(220) The Commission recommends developing a multi-disciplinary approach, involving stakeholders as much as possible in the design and follow-up of the health surveillance programme. The role of ethical codes of conduct may be relevant for such type of situation. It also recommends the need to be prepared to take appropriate actions to address any unexpected changes in the health status of the population.

4.4.3. Accompanying measures

(221) To restore individual well-being and the quality of community life in the affected areas where people are allowed to reside, there is a need to develop accompanying measures beyond the protective actions themselves. A first objective is to re-establish technical networks (water, electricity, telephone, etc.), infrastructure (roads, railway lines, etc.), and the services necessary for public life (schools, hospitals, post office, banks, shops, social activities, etc.). It is also important to ensure the overall socio-economic development of the territories concerned (establishment of industrial zones; support for the maintenance and establishment of agricultural, industrial, and commercial activities; etc.).

(222) Dedicated research programmes should be considered to address the challenges of the rehabilitation process, notably in the fields of health, socio-economic and environmental consequences, agriculture, and fishing and forestry activities, but also for decontamination, waste management, and dismantling the damaged installation.

(223) Authorities should support citizen initiatives aimed at regaining control of the radiological situation (co-expertise processes, self-help protective actions, local projects, etc.). They should facilitate the establishment of dialogues involving representatives of the affected population and relevant experts (e.g. health, radiological protection, agriculture authorities, etc.). These dialogues aim to gather and share information, and should favour a common assessment of the effectiveness of strategies driven by the population and the authorities. As these citizen initiatives require resources, it is necessary to establish appropriate mechanisms to ensure legitimacy, transparency, and fairness of the decision-making process to allocate resources (Eikelmann et al., 2016).

(224) Past experience has shown that communities who have participated in the rehabilitation process feel the need, after a while, to develop projects in the domains of memory, culture, and education. This memory is not only for commemoration but also serves as a living reminder to raise awareness, to maintain vigilance, and to pass on experience and so build the future. In this regard, the involvement of the education system (schools and universities) is a crucial way for the transmission of experience to the next generation.

(225) The Commission recommends that due attention should be paid to the development of accompanying measures to support citizen initiatives and projects in the domains of memory, culture, and education, which contribute to decent and sustainable living conditions for the present and future generations.

4.5. Evolution and termination of long-term protective actions

(226) In the long-term phase, exposures of people, fauna, and flora are reduced gradually over time due to the combined effects of protective actions and natural

processes such as radioactive decay. As a result, years after a nuclear accident (or even decades in the case of a severe accident), it is advisable to consider whether to maintain, modify, or terminate protective actions. Such a decision should be taken with the involvement of the relevant stakeholders. As a wide range of protective actions can be implemented over different timescales during the long-term phase, it is not necessarily relevant to terminate all actions simultaneously; an action can be terminated when it has achieved its purpose, or if its continued application would cause more harm than good in the broadest sense.

(227) The fact that the exposures are below the reference level does not automatically mean the end of the long-term phase, as there is a possibility of further reducing them in compliance with the principle of optimisation, and it is advisable to maintain vigilance in order to avoid any increases in exposure. The Commission recommends maintaining an appropriate long-term monitoring programme and transmission of the practical radiological protection culture, even when protective actions are terminated, to engender continued vigilance about the residual radiological situation and its evolution.

5. PREPAREDNESS PLANNING FOR A LARGE NUCLEAR ACCIDENT

(228) Preparedness planning is an important process in preparing the strategy for the protection of people and the environment in the case of a nuclear accident. For the early and intermediate phases, this preparation relies on the development of preplanned protective actions for postulated scenarios, based on hazard assessment. For the long-term phase, preparedness aims to identify the societal, environmental, and economic vulnerabilities of potentially affected areas, and to develop guidelines that are sufficiently flexible to cope with whatever happens in reality (Schneider et al., 2018).

(229) A prerequisite to preparedness is acknowledging the possibility that a nuclear accident could occur, and the need to develop awareness, if not among the general population, at least among all organisations that would be potentially involved in the management of the post-accidental phases. Although it is difficult to envisage the population being prepared in advance of a nuclear accident, the Commission recommends that key representative stakeholders should participate in preparedness planning for all phases of an accident.

(230) Preparedness planning needs to involve those responsible from different organisations in developing mechanisms for communication and co-ordination between them, and a framework to guide the decision-making processes. In view of the possible transboundary consequences of an accident, it is also important to prepare for coordination with similar organisations in neighbouring countries and international organisations.

(231) Practically, preparedness plans should contain a set of appropriate protective actions and arrangements for implementing them, including reference levels. Provisions for the deployment of necessary equipment for the characterisation of the radiological situation and the implementation of the co-expertise process should also be considered. In addition, specific communication schemes to inform the public and other stakeholders, as well as provisions for the training of those to be involved in the response, should be developed. These plans should be subject to regular exercises involving the various stakeholders.

(232) Preparedness plans should address the details of planning, appropriate for the range of scenarios foreseen, keeping in mind the necessary flexibility for responding according to the actual situation. They should also consider both radiological and non-radiological factors. For the early phase, they should also include predetermined radiological criteria for protective actions that need to be implemented promptly, such as sheltering, evacuation, and stable iodine distribution.

(233) The preparation of detailed plans for accident and post-accident management is a national responsibility. In addition, there is co-operation between countries and at an international level, which is reflected in the development of detailed requirements, practical guidance, and joint exercises (IAEA, 2015b; Duranova et al., 2016; NEA, 2018; Schneider et al., 2018). The Commission expects that the recommendations provided in this publication will ultimately be used by national and international organisations.

6. CONCLUSIONS

(234) A large nuclear accident is an unexpected event that profoundly destabilises individuals and society, generates a complex situation, and requires mobilisation of considerable human and financial resources. Beyond the legitimate concerns of all those affected regarding the deleterious health effects of radiation exposure, the societal, environmental, and economic consequences of a major nuclear accident, and the response to that accident, may be considerable and last for a very long time. Given the complexity of the situation created by the accident and the extent of its consequences, radiological protection, although indispensable, only represents one dimension of the contributions that are likely to need to be mobilised to cope with the issues facing all affected individuals and organisations.

(235) In such a context, the first objective of radiological protection is to prevent the occurrence of severe immediate radiation-induced damage to tissues and organs, and to reduce the risk of cancer and hereditary effects in the future to as low as reasonably achievable, taking societal, environmental, and economic considerations into account. This is achieved through a set of complementary protective actions that are initiated at the start of the early phase, and may last for several decades. Protective actions are selected by taking into account radiological and non-radiological considerations.

(236) Experience from past nuclear accidents has shown that, despite the desire to do more good than harm, and to maintain and reduce radiological exposures to as low as reasonably achievable in accordance with the principles of justification and optimisation, protective actions adopted during the early, intermediate, and long-term phases can also be a source of negative consequences and additional complexity.

(237) Operationally, the main recommendation of the Commission to mitigate the potential effects of radiation on health and the environment relies on the principle of optimisation, with the use of criteria based on reference levels to select and implement protective actions, taking into account the characteristics of the exposure situation on-site and off-site and the categories of exposed individuals. The reference levels recommended by the Commission for optimisation of protection of people in this publication are summarised in Table 6.1. The relevant reference levels recommended by the Commission for the protection of non-human biota are presented in *Publication 124* (ICRP, 2014).

(238) The recommendations provided in this publication have been developed taking into account the experience gained from previous nuclear accidents, and the most advanced scientific knowledge on the health and environmental effects of radiation. They have also been elaborated with the objective of putting radiological protection at the service of rehabilitating living and working conditions and the quality of life of affected communities. To achieve this objective, the Commission emphasises the crucial importance of involving stakeholders.

(239) Experience from the Chernobyl and Fukushima accidents has shown that radiological protection experts and professionals engaged in the early, intermediate,

Table 6.1. Reference levels for guiding the optimisation of protection of responders and members of the public during the successive phases of a nuclear accident.

	Early Phase	Intermediate Phase	Long-Term Phase
Responders on-site	100 mSv or below* Could be exceeded in exceptional circumstances[†]	100 mSv or below* May evolve with circumstances*[†‡]	20 mSv per year or below
Responders off-site	100 mSv or below* Could be exceeded in exceptional circumstances[†]	20 mSv per year or below[‡] May evolve with circumstances	20 mSv per year or below in restricted areas not open to the public Lower half of the 1 to 20 mSv per year band in all other areas[¶]
Public	100 mSv or below for the entire duration of both the early and intermediate phases[§]		Lower half of the 1 to 20 mSv per year band with the objective to progressively reduce exposure to levels towards the lower end of the band, or below if possible[¶]

*Previously, the Commission recommended selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendations recognise that the most appropriate reference levels may be lower than this band under some circumstances.
[†]The Commission recognises that higher levels in the range of a few hundred millisieverts may be permitted to responders to save lives or to prevent further degradation at the facility leading to catastrophic conditions.
[‡]As some responders may be involved in both the early and intermediate phases, the management of exposures should be guided by the objective to keep the total exposure during these phases below 100 mSv.
[§]Previously, the Commission recommended the selection of reference levels in the band of 20–100 mSv for emergency exposure situations. The current recommendation recognises that, in some circumstances, the most appropriate reference level may be below 20 mSv.
[¶]This clarifies the expression 'lower part' as used in *Publication 111*.

and long-term phases should, beyond mastering the scientific basis of radiological protection and its practical implementation, co-operate with affected people within co-expertise processes in accordance with the core and procedural ethical values underpinning the radiological protection system (ICRP, 2018).

(240) For this purpose, experts and professionals should adopt a prudent approach to manage exposures, seek to reduce inequities in exposures, take care of vulnerable groups, and respect the individual decisions of people while preserving their autonomy of choice. Experts and professionals should also share the

information they possess while recognising their limits (transparency), deliberate and decide together with the affected people what actions to take (inclusiveness), and be able to justify them (accountability). The issue at stake is not to make people accept the risk, but to support them to make informed decisions about their protection and their life choices (i.e. respect their dignity).

7. INTRODUCTION TO THE ANNEXES: AN OVERVIEW OF THE CHERNOBYL AND FUKUSHIMA NUCLEAR ACCIDENTS

(241) The two following annexes provide a brief historical overview of the Chernobyl and Fukushima nuclear accidents. The intention is not to give a detailed presentation of the different aspects of these two major accidents, but to highlight the most significant aspects in terms of radiological protection. The presentation of each accident is in line with the main text with regard to the successive phases: early, intermediate, and long-term. The objective is to illustrate the latter by highlighting the events and decisions which, over the years, have marked the management of these two accidents, and which have served as a reference for the development of the present recommendations.

(242) Readers interested in more details can refer to the documents produced by the main international organisations, which contributed significantly to the analysis of the events and consequences of the Chernobyl and Fukushima accidents (IAEA, 1991, 2015a; WHO, 1995, 2012, 2013; UNSCEAR, 2000, 2011, 2013, 2018; NEA, 2002, 2013). To aid the reader, references to these documents are shown in the annexes as well as being part of the full set of references.

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ANNEX A. THE CHERNOBYL NUCLEAR ACCIDENT

A.1. Introduction

(A1) The Chernobyl accident occurred on 26 April 1986 at 01:23 h in Unit 4 of the Lenin nuclear power plant, located on a tributary of the Dnieper River approximately 15 km from Chernobyl and 110 km from Kiev. At that time, the power plant was in the Ukrainian Soviet Socialist Republic in the USSR (see Fig. A.1). During a low-power engineering test, safety systems had been switched off, and improper operation of the reactor led to an uncontrollable power surge resulting in successive steam explosions that severely damaged the reactor building and completely destroyed the reactor (UNSCEAR, 2000). The accident was classified as level 7, the highest on the International Scale of Nuclear Events (IAEA, 2013).

(A2) The radionuclide releases from the damaged reactor occurred mainly over a 10-day period with variable release rates. The deposition of radioactivity on the ground largely affected the territories of Belarus, Russia, and Ukraine surrounding the reactor, although some radioactivity was found in practically every country of the northern hemisphere (UNSCEAR, 2000).

Fig. A.1. Location of Chernobyl.

A.2. Early and intermediate phases

(A3) The early phase started on 26 April 1986 with the accident. At the beginning of May 1986, the release of radionuclides into the environment had decreased by several orders of magnitude. During May 1986, actions were implemented to limit further releases (IAEA, 1991). This can be considered as the end of the early phase and the beginning of the intermediate phase.

(A4) On 26 April 1986, the Soviet Government established the Commission on Mitigation of the Consequences of the Chernobyl Accident. This Commission, chaired by the Deputy Prime Minister of the former USSR, included various experts (physicians, specialists in emergency situations and in radiological protection, etc.) as well as government officials. Although experts in all aspects of emergency situations were involved in the activities of the Commission, only government officials had the right to make decisions.

(A5) On-site, the intermediate phase is considered to have ended with the completion of the sarcophagus in November 1986, which contained and secured the radiation source. Off-site, the intermediate phase is considered to have ended during the period February–May 1991, with the adoption of laws related to management of the long-term phase.

(A6) During the early phase, the authorities implemented sheltering, evacuation, distribution of stable iodine, and food restrictions. During the intermediate phase, further actions were implemented such as relocation, decontamination, and waste management. However, in both phases, this was not always carried out in a timely and systematic way in all affected areas.

(A7) During the early and intermediate phases, many civilian and military responders were involved in mitigation of the consequences of the accident on-site and off-site. Some of these individuals received substantial levels of exposure, inducing early severe tissue/organ damage, and cancers in the longer term.

A.2.1. Radiation monitoring

(A8) In the first few days following the accident, an extensive programme of exposure rate measurements was undertaken around the Chernobyl nuclear power plant. As a result, the first map of exposure rates was prepared on 1 May 1986. The radiation monitoring programme implemented in the Soviet Union following the Chernobyl accident included extensive measurements of ambient dose rates, foodstuff contamination, and contamination of soil and grass samples. The focus was on radiologically important radionuclides: isotopes of iodine, caesium, strontium, and plutonium. In the early phase, the delay in initiating the monitoring programme resulted in a lack of radioiodine measurements in soil samples. Due to the lack of equipment and specialists, and the vast areas to be monitored, detailed characterisation of the radiological situation took several years. Beyond the affected areas in the Soviet Union, many affected European countries also carried out their own measurements (EC, 1992).

A.2.2. Levels of contamination

(A9) Between 26 April and mid-May 1986, the radioactive releases dispersed a large range of radionuclides, such as radioiodine and radiocaesium, over most countries in the northern hemisphere.

(A10) Ukraine, Belarus, and Russia were the Soviet republics most affected by the fallout. These large affected areas (almost 150,000 km^2) received approximately 60% of the total radioactivity released: on average, caesium-137 (Cs-137) exceeded 37,000 Bq m^{-2} and often reached several hundred thousand becquerels per square metre (see Fig. A.2). Across Europe, the radioactivity was deposited inhomogeneously according to the distance from the source and the prevailing weather conditions (see Fig. A.3).

(A11) In these republics, the authorities considered areas exceeding 37,000 Bq m^{-2} of Cs-137 as contaminated and eligible for protective actions. Based on this criterion, the affected areas were 46,500 km^2 in Belarus, 57,700 km^2 in Russia, and 41,900 km^2 in Ukraine. Areas with plutonium contamination were mainly limited to the vicinity of the damaged installation, while for strontium, the area extended up to 100 km around the plant (UNSCEAR, 2000).

(A12) In Europe, deposition of caesium exceeding 37,000 Bq m^{-2} was found in Scandinavia (southern Finland, central and eastern part of Sweden, central Norway), central Europe (especially in the south of Romania, at the border between the Czech Republic and Poland), Austria and the north of Greece, as well as in smaller areas in the UK, Switzerland, Germany (mainly Bavaria), and Italy.

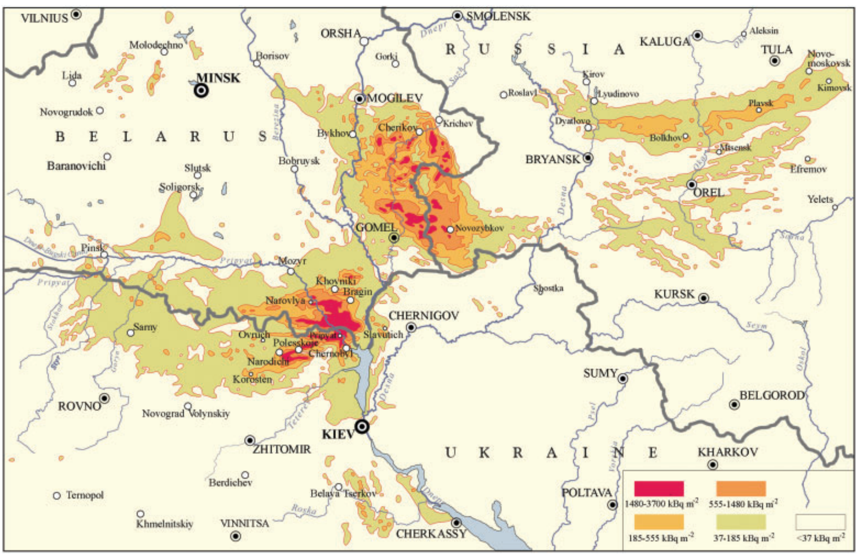


Fig. A.2. Surface ground deposition of Cs-137 in areas of Belarus, Russia, and Ukraine near the accident site (IAEA, 1991).

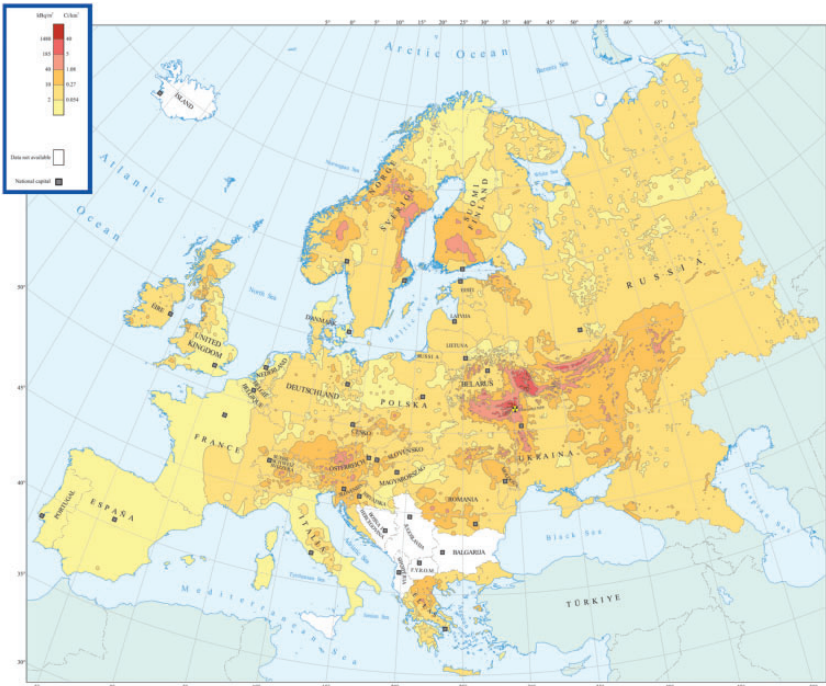


Fig. A.3. Map of Cs-137 deposition after the Chernobyl accident across Europe. Source: European Atlas EC / IGCE 1998. No data are available for the Balkans.

A.2.3. Levels of individual exposure

(A13) During the early phase, the main exposure pathway for members of the public was from the intake of radioactive iodine. In May–June 1986, a large monitoring study looking at the iodine content of the thyroid was conducted in Belarus, Russia, and Ukraine. In total, direct thyroid measurements for more than 400,000 people were carried out by the end of June 1986 (Zvonova and Balonov, 1993; Likhtarev et al., 1996; Stepanenko et al., 1996; Gavrilin et al., 1999).

(A14) Consumption of fresh cows' milk from animals who had been put to pasture before the accident was the main pathway of radioactive intake for the majority of people. This resulted in large thyroid doses, especially to children living in rural areas in the vicinity of the damaged reactor. Approximately 95% of small children under 3 years of age from evacuated and non-evacuated villages in the three southern regions of Gomel Oblast in Belarus received a thyroid dose higher than 0.25 Gy. Among them, a substantial number received thyroid doses higher than 2.5 Gy (Savkin and Shinkarev, 2007). The highest estimates of thyroid doses to children derived from direct thyroid measurements were found to be as high as 50 Gy (Shinkarev et al., 2008).

(A15) In addition to radioactive iodine exposure, the doses received by the populations of affected areas during the early and intermediate phases largely resulted from external exposure to radioactive caesium deposited on the ground, and internal exposure due to consumption of contaminated foodstuffs. The average effective doses received by the residents of affected areas are estimated to be approximately a few tens of millisieverts. The median effective dose was approximately a few millisieverts. It is estimated that approximately 10,000 people received effective doses higher than 100 mSv (UNSCEAR, 2000).

A.2.4. Responders

(A16) During the early phase, approximately 600 responders, including staff from the power station, firemen involved in the initial response, security personnel, and staff from the local medical facility, were on-site at the power station during the night of the accident. Later on, about 600,000 responders, the so-called 'liquidators' (civilian or military personnel), were involved in the removal of radioactive debris, construction of the sarcophagus, and construction of settlements for reactor personnel and responders. This included responders in charge of transport and security, as well as scientists and medical staff (UNSCEAR, 2000).

(A17) The most significant exposures were due to external irradiation. Acute radiation sickness was confirmed for 134 responders. Forty-one of these responders received whole-body doses from external irradiation less than 2.1 Gy. Ninety-three responders received higher doses and had more severe symptoms of acute radiation sickness: 50 responders received doses of 2.2–4.1 Gy, 22 responders received doses of 4.2–6.4 Gy, and 21 responders received doses of 6.5–16 Gy. Their doses were estimated mainly using clinical dosimetry methods (i.e. on the basis of blood components and/or cytogenetic parameters of blood lymphocytes). In total, 28 people died within a few months of the accident (UNSCEAR, 2000).

(A18) Prior to the accident, the dose criterion for workers was 50 mSv per year in normal conditions, and in the case of an incident/accident, this value could be increased to 250 mSv with informed consent from the concerned personnel (SRS-76, 1977). This regulation was applied to the responders in 1986 at the time of the accident.

(A19) In 1987, the maximum annual dose criterion for responders was lowered to 100 mSv. However, a dose of up to 250 mSv was allowed by the Ministry of Health for a limited number of responders for the implementation of extremely important interventions. In 1988, the dose criterion was reduced to 50 mSv for all workers including responders, except those involved in decontamination of the engine hall inside the sarcophagus; for these responders, the annual dose criterion was kept at 100 mSv. From 1989 onwards, the dose criterion was set at 50 mSv for all responders, without exception (Kryuchkov et al., 2011).

(A20) Notably, for military responders, a dose criterion of 500 mSv, corresponding to radiation exposures allowed during war time, was applied until 21 May 1986. It was then lowered to 250 mSv by the Ministry of Defense (Chvyrev and Kolobov, 1996). From 1987 onwards, the dose criterion was the same for military and civilian responders.

(A21) All responders were recorded in an official registry established in 1986. This registry included estimates of their exposures due to external irradiation, which was the predominant pathway of exposure. The registry data showed that the average recorded exposures decreased from approximately 170 mSv in 1986 to 130 mSv in 1987, 30 mSv in 1988, and 15 mSv in 1989 (UNSCEAR, 2000). It is recognised that these values have associated uncertainties.

(A22) Due to the abundance of radioactive iodine in the vicinity of the reactor, responders who were on-site during the first few weeks after the accident may have received substantial thyroid doses due to internal irradiation. On the basis of a limited number of measurements made between 30 April and 7 May 1986 on more than 600 responders, their thyroid doses were estimated to be, on average, 0.21 Gy. However, it is important to note that internal doses due to intakes of radioactive iodine were small in comparison with external doses received after May 1986 (UNSCEAR, 2000).

A.2.5. Protective actions during the early phase

A.2.5.1. Sheltering

(A23) A recommendation on sheltering was announced by the Government Commission on the day of the accident (26 April 1986) for the residents of Prypiat, located approximately 3 km from the reactor site, where most of the nuclear power station workers lived with their families. Approximately 25% of the total population of 50,000 residents of Prypiat limited the time spent outdoors (Likhtarev et al., 1994). Residents in rural settlements in the vicinity of the nuclear installations were not officially notified of the accident, and consequently had no official information on the need to shelter.

A.2.5.2. Evacuation

(A24) On 27 April 1986, between 37 and 40 h after the accident, the authority of Kiev Oblast organised the evacuation of all residents of Pripyat by buses, trains, and cars. This was due to the continued release of radionuclides from the damaged reactor and an increase in exposure rates in various parts of the town. Approximately 9000 residents self-evacuated (Alexakhin et al., 2004). The evacuees were expected to be away from Prypiat for a limited period and were only permitted to take a few belongings, such as documents and their pets. The evacuees were moved to different areas and settlements of Ukraine, primarily located in Kiev Oblast. Approximately 5000 members of staff from the Chernobyl nuclear power plant remained in Pripyat after the accident, and were subsequently relocated to various places in surrounding areas.

(A25) Information available on 1 May 1986 suggested that projected exposures did not warrant evacuation for most people living close to the power plant. However, a large increase in the temperature of the fuel remaining in the reactor core was observed which, according to specialists at Kurchatov Institute, Moscow, had the potential to breach the bottom of the core, resulting in a significant further release of radioactive material. Exposure estimations showed that the occurrence of serious deterministic effects could extend as far as 30 km from the damaged reactor.

(A26) On 2 May 1986, the Government Commission made the decision to evacuate the entire population within a 30-km radius due to uncertainties at the reactor and in the prevailing meteorological conditions. This evacuation (approximately 50,000 residents) took place between 2 and 7 May 1986. At the same time, approximately 50,000 cattle, 13,000 pigs, 3300 sheep, and 700 horses were evacuated from the 30-km zone (Nadtochiy et al., 2003). More than 20,000 agricultural and domestic animals, including cats and dogs, that were not evacuated were killed and buried.

A.2.5.3. Stable iodine

(A27) Stable iodine tablets had not been pre-distributed to people living in the areas neighbouring the Chernobyl nuclear power plant. Hence, on 26 and 27 April 1986, medical officers went to houses, schools, and kindergartens in Prypiat providing members of the public with tablets. It is estimated that the percentage of residents who took them reached 62% by the afternoon of 27 April 1986 (Likhtarev et al., 1994). Prypiat was the only settlement where administration and use of stable iodine were effective. Distribution of iodine tablets in villages within the 30-km zone was initiated at approximately the same time as evacuation. According to the results of interviews with people living in the 30-km zone, the distribution of tablets mainly occurred on 1–4 May 1986 in Belarus and on 2–7 May 1986 in Ukraine (UNSCEAR, 2000). However, this was too late to be really effective. In rural areas outside the 30-km zone, stable iodine was not used during the early phase of the accident (Uyba et al., 2018).

A.2.5.4. Restrictions of the consumption of foodstuffs

(A28) No restrictions were made on the consumption of contaminated foodstuffs during the early phase of the accident, as the public had not been notified about the radiological situation in the first few days after the accident (until 5 May 1986). The residents of affected areas consumed cows' milk contaminated with radioactive iodine, and this resulted in high doses to the thyroid, especially among young children.

A.2.6. Protective actions during the intermediate phase

(A29) In May 1986, the Main State Sanitary Physician of the USSR adopted a dose criterion of 100 mSv for restricting exposure of the public during the first year (from 26 April 1986 to 25 April 1987). On 23 April 1987, this dose criterion was reduced to 30 mSv for the second year following the accident. A year later, on 18 July 1988, the annual dose criterion was further reduced to 25 mSv for the third and fourth years following the accident.

(A30) The Main State Sanitary Physician also defined three areas (zones), based on exposure rates, where external exposure would be restricted during the first year following the accident:

- the 'exclusion zone', areas subject to permanent relocation;
- the 'temporal evacuation zone', areas where relocated residents could return after 'normalisation' of radiological conditions; and
- the 'strict control zone', areas where children and pregnant women were excluded for the summer of 1986.

A.2.6.1. Relocation

(A31) From the middle of May to the middle of August 1986, approximately 9000 residents of 40 Belarusian and Ukrainian villages outside the 30-km zone were relocated due to assignment of those villages to the exclusion zone because of relatively high exposure rates (Alexakhin et al., 2004).

(A32) In August 1986, the Government Commission ordered Goskomhydromet, the Ministry of Public Health, and the Ministry of Defence of the USSR to conduct a detailed radiation monitoring survey for the 47 less-affected settlements located in southern and western parts of the exclusion zone to determine whether the residents could return to their homes. The monitoring results indicated that the residents of 27 rural settlements (12 in Belarus and 15 in Ukraine) could return once the sarcophagus was in place. The total exposure (external plus internal) of these residents during 1987 was estimated to be less than 30 mSv. Residents of the 12 Belarusian settlements were allowed to return by the winter of 1986–1987. In contrast, the Ukrainian authorities considered that it was economically and socially inappropriate to permit the return of residents to the 15 settlements inside the 30-km zone.

A.2.6.2. Restrictions on the consumption of foodstuffs

(A33) At the beginning of the intermediate phase, intake of radioactive iodine through consumption of foodstuffs, notably milk, was still the main source of internal exposure of the public. Consequently, on 6 May 1986, the Main State Sanitary Physician of the USSR introduced radiological criteria for milk and water, dairy products, and leafy vegetables to control radioactive iodine in foodstuffs and drinking water. Milk exceeding the criteria was processed into butter, cheese, etc. to take advantage of the radioactive decay. On 30 May 1986, the Main State Sanitary Physician of the USSR introduced new criteria for all relevant radionuclides and these were revised regularly (Alexakhin et al., 2004).

A.2.6.3. Decontamination

(A34) Decontamination work commenced in affected settlements at the end of May 1986. It included: removal of contaminated soil and its replacement with 'clean' soil; dismantling of items that could not be cleaned; asphalting of streets, roads, and pavements; roof replacement; and burial of any waste arising at temporary storage areas. Decontamination work was undertaken primarily by the chemical branch of the USSR armed forces and the civil defence forces. Radiological criteria were established for selecting places to be decontaminated, and these were revised regularly (Alexakhin et al., 2004).

(A35) Decision-making on decontamination not only considered the level of radioactive contamination, but also the social and economic significance of the affected places and items. From 1986 to 1987, a major improvement in the radiological situation was achieved through a significant reduction in the levels of radioactivity in frequently visited places in the settlements. This resulted in a reduction in the external dose for various professionals and some age groups (e.g. children) by an average of 30%. By 1989, full decontamination of settlements was almost complete. Overall, the average efficiency of decontamination was estimated to not exceed 10% (Alexakhin et al., 2004).

A.2.6.4. Agricultural protective actions

(A36) During the intermediate phase, a whole range of agricultural protective actions were implemented progressively in the affected areas such as: deep ploughing of meadows, removal of topsoil, addition of fertilisers and chemicals to contaminated soils, banning cattle slaughter, provision of clean feed for animals, exclusion of crops with a high level of radioactivity, and change in land use (IAEA, 1991).

(A37) Agricultural production was stopped in Russia in areas where soil contamination exceeded 1,480,000 $Bq\,m^{-2}$.

A.2.6.5. Provision of information

(A38) There was no early notification of the public about the radiological situation following the Chernobyl accident. On the contrary, the results of measurements of exposure rate, levels of contamination of various radionuclides, etc. were classified.

This contributed to the distrust of the public in the information provided by the state and local authorities relating to the accident. Radiological data only became accessible to the public 1 year after the accident. However, this was not sufficient to improve public confidence.

A.3. Long-term phase

(A39) Schematically, the protective actions adopted in the early 1990s relied on further restriction of human presence in the affected areas (mandatory or voluntary relocation), and on strictly controlling the level of contamination in foodstuffs and the whole-body contamination of individuals. Many protective actions were focused on control and improvement of the radioactive contamination of agricultural products in collective farms; private production was restricted as much as possible because of difficulty in controlling and monitoring its quality.

A.3.1. The regulatory framework

(A40) To prepare for the long-term phase, on 22 November 1988, the USSR National Commission for Radiation Protection recommended a dose criterion of 350 mSv for lifetime exposure for members of the public, during 70 years, including exposure from the time of the accident in 1986 onwards (Ilyin, 1995). This recommendation provoked a lively debate between the authorities and experts at state and republic levels, which led the USSR Government to ask IAEA to provide its expertise (IAEA, 1991). In 1990–1991, a team of independent international experts visited the USSR to evaluate the radiological consequences of the Chernobyl accident.

(A41) Experts reviewed the concepts, methodologies, and estimated exposures provided by the USSR scientists. IAEA concluded that the proposed dose criterion 'generally exceeded what would have been strictly necessary from a radiological protection viewpoint'. It was also 'recognized that there are many social and political factors to be taken into consideration and the final decision must rest with the responsible authorities' (IAEA, 1991). Finally, due to pressure from the public and mass media, the Soviet Government just renounced its recommendation in year.

(A42) By the end of 1991, the USSR had split into 15 separate countries. Governments of Belarus, Russia, and Ukraine adopted national laws 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 affected areas. The objective of these laws was mainly to address long-term issues through a series of protective actions and compensation mechanisms, designed mainly based on radiological criteria.

(A43) In Belarus, for instance, two laws were published to define the principles governing the social protection of the affected population and the status of affected 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' (responders), populations, and workers in the affected areas, as well as the compensation allocated in each case. The second law, voted in November 1991, which concerned 'the legal status of the affected 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. 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.

(A44) In 2001, the Belarus 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 restrictions, the average total exposure (external and internal) of the population should not exceed 1 mSv per year (excluding background).

(A45) The protection schemes adopted in Ukraine and Russia have been globally similar to those adopted in Belarus, with some specificities related to national and local conditions.

A.3.2. Radiation monitoring and exposure

(A46) During the long-term phase, individual radiation monitoring was widely adopted in affected areas, based on the use of thermoluminescent dosimeters and whole-body counters to assess individual external and internal exposures, respectively.

(A47) Data of external exposure of members of the public revealed wide variation between settlements, large individual dose distributions, and time dependency. They showed that the urban population was exposed to a lower external dose, approximately by a factor of 2, compared with the rural population living in areas with similar levels of radioactive contamination. Data of internal exposure showed that people who received exposures (not including dose to the thyroid) higher than the average by a factor of 2–3 were those who lived in rural areas in single-storey homes, and who consumed large amounts of wild foods such as game meats, mushrooms, and berries (IAEA, 2006).

(A48) Whole-body exposure was monitored in the context of a German study in approximately 300,000 people from 1991 to 1993 in Belarus, Russia, and Ukraine (Hill and Hille, 1995). For 90% of people monitored, the internal exposures from radioactive caesium were found to be less than 0.3 mSv per year. A French study performed in the Bragin region in Belarus in the early 2000s among 2500 school children showed that the average whole-body contamination was in the range of 25 $Bq\,kg^{-1}$, and also revealed children with contamination up to a few hundreds of becquerels per killogram (Bataille et al., 2008). Converted into dose, the average internal exposure was estimated to be in the range of 0.05 mSv per year, with 1% of the group having exposure of approximately 1 mSv or more (ICRP, 2009).

(A49) It has been estimated that the vast majority of the 5 million people residing in the affected areas of Belarus, Russia, and Ukraine in the early 2000s received annual exposures of less than 1 mSv. The number of residents of the affected areas in the three most affected countries that received an annual exposure of more than 1 mSv can be estimated to be approximately 100,000 people (IAEA, 2006).

A.3.3. Monitoring of foodstuffs

(A50) During the long-term phase, monitoring of foodstuffs was continued and further developed to cover both the needs of the agricultural sector (collective and private farms) and those related to the self-production of residents, as well as to wild products such as mushrooms, berries, and game. Measurement data showed that the level of contamination in foodstuffs decreased progressively in the agricultural sector, except for wild products.

(A51) For example, in Belarus, the number of collective farms with milk measurements above the radiological foodstuff criteria was reduced by a factor of 5 between 2001 and 2005. Between 2000 and 2010, the number of villages in which milk measurements from private farms exceeded this criterion was reduced by a factor of almost 20. Measurements of wild products revealed large seasonal variations without any significant reduction in the average annual level of contamination (Belarusian Ministry for Emergency Situations, 2011).

(A52) As far as the control of foodstuffs is concerned, authorities have adopted a pragmatic approach by reducing the radiological criteria as the situation improved.

A.3.4. Long-term protective actions

A.3.4.1. Permanent relocation

(A53) On 12 May 1991, a special federal law was settled in the USSR – 'Law on social protection of citizens affected by the Chernobyl disaster' – including a revision of the status of the affected areas, based on the level of ground contamination, as follows:

- the 'exclusion zone', corresponding to the affected area from which all residents were relocated in 1986. Permanent residence of the population is prohibited and economic activity and nature management are limited;
- the 'relocation zone' divided into two parts: affected areas where the average annual exposure to the residents might be greater than 5 mSv and from which the population must be relocated, and other affected areas for which the residents have to decide to self-move voluntarily or decide to remain in the areas with the corresponding compensations;
- the 'residence zone with the right for relocation', where the average annual exposure might be greater than 1 mSv, and people who decide to self-move voluntarily have the right to receive the corresponding compensations; and
- the 'residence zone with preferential socio-economic status', where the average annual exposure to the residents in those settlements should not exceed 1 mSv.

Fig. A.4. Cow in a stable licking ferrocine (Belarus).

(A54) Following this law, wide-scale relocation was carried out during the 1990s in the most affected areas, mainly in Belarus and Ukraine. For example, in Belarus, approximately 140,000 people have been mandatorily relocated, and approximately 200,000 people left the affected areas voluntarily (Belarusian Ministry for Emergency Situations, 2011).

A.3.4.2. Agricultural protective actions

(A55) Most of the agricultural protective actions implemented during the intermediate phase continued during the long-term phase. However, research in the agrochemical field, in particular carried out during the 1990s, made it possible to improve their efficiency by optimising soil fertilisation according to local situations. This allowed the modernisation and respecialisation of farms, the selection of crops and varieties, and the alternative use of land. The use of a mixed diet for dairy cows enriched with caesium-binding ferrocine (Prussian blue) (See Fig. A.4) and separate diets for animals according to their age have made it possible to significantly improve the quality of milk and meat (Bogdevitch, 2003; Belarusian Ministry for Emergency Situations, 2011).

A.3.5. Health surveillance

(A56) After the Chernobyl accident, the USSR Government initiated a programme of compulsory registration and continuous health monitoring of responders as well as residents of the most affected areas, including their children. By the end of 1991, the All-Union Distributed Clinico-Dosimetric Registry had recorded information for approximately 660,000 people. After the dissolution of the USSR into independent states, national Chernobyl registries continued to operate, but the comparability of data was more limited. A number of specialist population-based registries were set up in Belarus, Russia, and Ukraine, including those for thyroid cancer and haematological malignancies.

(A57) International collaborations started to develop in 1990, and have since played a substantial role in assessing the health consequences of the Chernobyl accident. A number of epidemiological studies were conducted in Belarus, Russia, and Ukraine concerning evacuees, residents of affected areas, and responders. Most studies focused on thyroid cancer in children, leukaemia, and other cancers, but some also considered cardiovascular diseases, cataracts, or congenital malformations.

(A58) One major finding is that the Chernobyl accident resulted in a dramatic increase in the rate of thyroid cancers among members of the public who had been exposed as infants or young children at the time of the accident. A review of data available from 1990 to 2005 in the affected areas (the whole of Belarus and Ukraine, and the four most contaminated oblasts of Russia) showed that the number of cases of thyroid cancer among those who were under 18 years of age in 1986 approached approximately 7000 (UNSCEAR, 2011). A more recent review covering the 1991–2015 period showed that the total number of cases of thyroid cancer was almost three times higher (UNSCEAR, 2018).

(A59) Some evidence exists of an increase in the incidence of leukaemia among groups of responders (UNSCEAR, 2011; Zablotska et al., 2013). Studies of an increase in the frequency of other health effects are not conclusive. Thirty-five years after the accident, they have not shown a clear link between the dose received and the increase in leukaemia and solid cancers – such as colon, lung, or breast cancer – among the inhabitants of the affected territories and the evacuees. However, for these types of cancers, it cannot be excluded that the time since the accident is still too short for a possible increase in frequency to be detectable. Likewise, for non-cancerous pathologies, such as congenital malformations and cardiovascular diseases, studies carried out are not conclusive.

(A60) Some studies have observed an increase in the frequency of cataracts and cardiovascular and cerebrovascular pathologies with the dose received in certain groups of liquidators. Current results do not allow the conclusion that the frequency of solid cancers – such as colon, lung, or breast cancers – has increased among liquidators. Finally, surveys performed more than 10 years after the accident among the affected population also revealed an increase in psychosocial problems, including suicides, attributed to lifestyle changes due to the presence of radioactivity (Bromet et al., 2011).

A.3.6. Emergence of the co-expertise process

(A61) The Soviet Union collapsed in 1991 and socio-economic conditions deteriorated drastically in Belarus, Russia, and Ukraine. Despite the efforts of the authorities in the early 1990s to disseminate information about the radiological situation and to act in a more open way, the public's concern over the presence of radioactivity and its potential consequences for health intensified, particularly for children.

Fig. A.5. Measurements at home by a resident during the ETHOS project.

Reinforced by the general loss of trust in the authorities and experts, a feeling of helplessness gradually developed among the people in the affected areas.

(A62) In this context, a group of French experts initiated the ETHOS pilot projects in Belarus in the mid-1990s with the support of national and local authorities; the aim was to involve the affected population and other stakeholders in the management of the radiological situation to improve both their protection and their living conditions (Hériard Dubreuil et al., 1999).

(A63) For 5 years, experts worked with the villagers to reduce the internal contamination of children, to restore the radiological quality of milk and meat produced in the villages, to manage the radioactive ashes resulting from the use of wood from surrounding forests, and to develop a practical radiological protection culture among children and young people. Tangible results were obtained in all of these areas, and the ETHOS project was recognised by the United Nations Development Programme (UNDP) as an important model to promote community-based programmes involving environmental education (UNDP, 2002).

(A64) The experience gained in the ETHOS project was the basis of the CORE programme (COoperation for REhabilitation of living conditions in Chernobyl affected areas of Belarus) implemented in Belarus from 2004 to 2008. This programme was an international initiative developed by the Chernobyl Committee of Belarus, notably supported by UNDP and other international organisations, with the objective of supporting local projects in four affected regions of Belarus in four areas of action: health, education and memory, economic development, and radiological quality (Trafimchick, 2005).

(A65) One of the radiological quality projects was the Radiation Monitoring project implemented in the Bragin region (Gomel Oblast). It aimed to reduce the whole-body contamination of the population, particularly among children, and to promote self-help protective actions. The Bragin project has illustrated the key role of measurements for involving affected people in the rehabilitation process, and to empower them in order to make informed decisions about their protection (See Fig. A.5). It also emphasised the role of dialogue in the interaction with different stakeholders (Bataille et al., 2008).

(A66) The ETHOS project and CORE programme demonstrated that the direct involvement of local stakeholders in the day-to-day management of a radiological situation is feasible. They also demonstrated that to be sustainable, management of a radiological situation by stakeholders should rely on a dynamic of economic development, relying primarily on individual initiatives of the local actors in partnership with national and international experts. These approaches foreshadowed the co-expertise process, which was further developed a decade later in local communities affected by the Fukushima accident.

A.3.7. Evolution and lifting of long-term protective actions

(A67) From the beginning of the 2010s, the lifting of protective actions in affected areas became a topical issue in the territories where the additional exposure levels had fallen below 1 mSv per year for the residents. This is a delicate issue as the declassification of these areas means the end of the compensation scheme put in place at the beginning of the long-term phase.

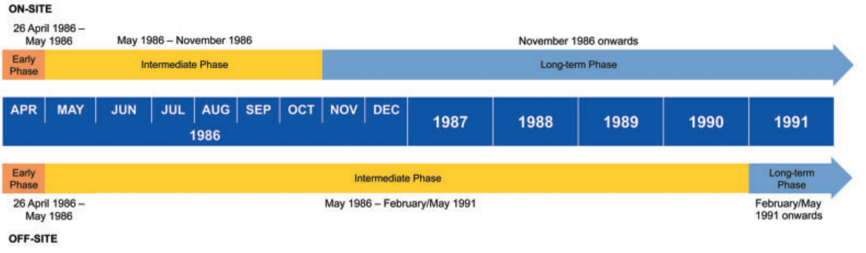
(A68) In this context, recommendations on criteria and requirements to allow lifting of long-term protective actions in affected settlements have been prepared by a group of scientists from Saint-Petersburg Research Institute of Radiation Hygiene (Barkovskii et al., 2012; Romanovitch et al., 2016). These recommendations provide radiological and non-radiological criteria that need to be met in order to terminate long-term protective actions, and to transit to a situation without restrictions in terms of radiological protection.

(A69) According to the radiological criterion, the average exposure of the 10% most exposed residents in a considered settlement should be less than 1 mSv per year. The exposure is related to the accident without including the natural background exposure. According to the non-radiological criterion, the agricultural activities in the considered settlement area should be performed without any restrictions and protective actions. In addition, the recommendations also mention the need for local authorities to set a plan for implementation and review of the lifting of long-term protective actions in consultation with the residents of the considered settlements.

(A70) However, the recommendations on the lifting of long-term protective actions have not yet been achieved in practice in Russia. They are still only recommendations. The local authorities in areas with settlements designated officially as ‘contaminated settlements’ are resistant to withdrawing this status as they fear social protests. Thus, in Russia, there are no legal regulatory documents determining the lifting of protective actions in affected areas, and no such lifting has occurred to date.

(A71) Due to the fact that the lifting of protective actions is a sensitive issue, at the time of writing, the above-mentioned recommendations have still not been implemented.

A.4. Timeline of the phases of the Chernobyl accident



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ANNEX B. THE FUKUSHIMA NUCLEAR ACCIDENT

B.1. Introduction

(B1) The Fukushima nuclear accident started on 11 March 2011 as a consequence of an earthquake followed by a tsunami, which severely damaged four of the six units of the Fukushima Daiichi nuclear power plant operated by the Tokyo Electric Power Company (TEPCO) located on the east coast of Japan, approximately 220 km north-east of Tokyo (see Fig. B.1).

(B2) The Great East Japan Earthquake with a magnitude of 9.0 occurred at 14:46 h on 11 March 2011, and generated a series of large tsunami that struck the east coast of Japan. The earthquake and tsunami caused devastation across a large part of Japan, with approximately 16,000 lives lost and approximately 2500 people missing.

(B3) Due to the earthquake, all off-site power supply to the nuclear power plant was lost, and the tsunami caused flooding of all power rescue systems, except for one diesel generator serving Unit 6. This resulted in a loss of cooling in Units 1–3 and in the spent fuel pool of Unit 4. As it was impossible to continue injecting water into the reactor pressure vessels in Units 1–3, the increased temperature of each reactor led to melting of the nuclear fuel and a series of hydrogen explosions in the reactor buildings of Units 1 and 3 on 12 and 13 March 2011, respectively. As a result of these

Fig. B.1. Location of Fukushima Daiichi nuclear power plant.

events, a large quantity of radioactive material was released into the atmosphere from Units 1, 2, and 3, and was deposited on land and in the ocean. The accident was classified as level 7, the highest on the International Scale of Nuclear Events.

B.2. Early and intermediate phases

(B4) The early phase started on 11 March 2011, with the announcement by the Japanese Government of the state of emergency. The main atmospheric radioactive releases occurred during the explosions and lasted until the end of March 2011. By mid-July 2011, the source of these releases was considered to be stabilised, and the Japanese Government and TEPCO announced that Step 1 of the roadmap, established for securing the damaged reactors, had been achieved (NERHQ, 2011c). This is considered to mark the beginning of the intermediate phase.

(B5) During the early phase, exceptional arrangements to ensure the protection of responders were adopted on-site. Off-site, a series of protective actions for the public were implemented during the early phase of the accident, including sheltering, evacuation and temporary relocation, administration of stable iodine, decontamination of people, and restrictions on the consumption of foodstuffs and drinking water. During the early phase, authorities also organised a series of public meetings in the affected areas to inform the population about the radiological situation (Takamura et al., 2019).

(B6) During the intermediate phase, several activities were undertaken to characterise the exposure pathways so that sufficient information could be gathered on where, when, and how people were exposed and could potentially be exposed in the future within the affected areas. This characterisation allowed plans to be established in August 2011 for the decontamination of these areas and the management of radioactive waste. In November 2011, ICRP initiated the Fukushima Dialogue to allow local stakeholders to exchange knowledge and information about the current and future challenges in the affected areas.

B.2.1. Radiation monitoring

(B7) Due to the loss of power supplies on 11 March 2011, all monitoring posts at the site boundaries became unavailable. Monitoring activities on-site began in the evening of 11 March 2011 using a monitoring vehicle, which measured a maximum value of 12 mSv h^{-1} in the morning of 15 March 2011 at the south-west of the site boundaries. As a result of the earthquake and tsunami, only one monitoring post among 23 within approximately 5 km of the plant was working. After 13 March 2011, Fukushima Prefecture and the Japanese Government worked together to conduct monitoring activities using monitoring vehicles, such as measurements of ambient dose rates, and air dust, environmental and soil samples. However, the initial monitoring activities did not proceed as expected due to the deterioration of road conditions caused by the earthquake and the lack of fuel (ICAFN, 2011).

(B8) In the intermediate phase, radiation measurements were carried out by various bodies such as ministries, agencies, municipalities, operators, non-profit organisations, and international organisations. To ensure consistency in the gathered information, the Japanese Government established a framework for the coordination of monitoring activities. The first comprehensive monitoring plan was launched in August 2011 to assess the overall impact of the accident on the affected areas, and to prepare future protective actions that might be adopted. Detailed monitoring was also carried out in response to people's demands for improving the quality of the environment around the plant, for children's health, and people's protection and security (NERHQ, 2011b).

B.2.2. Levels of contamination

(B9) In May 2011, the first map of aerial ambient dose-rate measurements within an 80-km radius of the plant was produced jointly by the Japanese Government and the US Department of Energy. The map showed the dose rate at 1 m above the ground surface (NERHQ, 2011a). The Japanese Government continues to conduct regular aerial monitoring to detect changes in the distribution of ambient dose rates in affected areas.

(B10) The radionuclide analysis of soil samples collected from approximately 2200 locations within approximately 100 km of the nuclear plant was carried out during June and July 2011. Ambient dose-rate measurements were also taken at the same sample locations. Detailed maps of the deposition densities of radioactive caesium and the distribution of ambient dose rates were produced in August 2011. Deposition densities of radioactive caesium higher than 3 million Bq m^{-2} were measured at several locations close to the plant (NERHQ, 2011b).

B.2.3. Levels of individual exposure

(B11) In June 2011, the Fukushima Health Management Survey was launched in Fukushima Prefecture under the auspices of Fukushima Medical University. It was intended to provide a retrospective and prospective overview on the overall health status of the affected population of Fukushima Prefecture, with some focus on particularly vulnerable groups. The survey included four distinct parts: (i) a thyroid examination for children aged less than 18 years; (ii) a health survey with an additional comprehensive blood test; (iii) a survey for pregnant women; and (iv) a survey on mental health and lifestyle. Part of the survey estimated the external exposure for the first 4 months after the accident, based on information on the movement of residents from a questionnaire, and on the daily ambient dose-rate maps. As a result, 99.4% of residents were estimated to have received doses less than 3 mSv, with a mean value of 0.8 mSv and a maximum value of 25 mSv (Ishikawa et al., 2015).

(B12) As part of the Fukushima Health Management Survey, internal exposures were measured for residents in the restricted area and the deliberate evacuation area by whole-body counting and bioassays of urine. The estimated internal doses due to Cs-134 and Cs-137 were reported to be less than 1 mSv (Momose et al., 2012).

(B13) From 26 March to 30 March 2011, a survey of thyroid exposure for infants and children was carried out in Iwaki City, Kawamata Town, and Iitate Village. From the results of 1080 children aged less than 15 years, no one exceeded the screening level of 0.2 $\mu Sv\,h^{-1}$, corresponding to an absorbed dose to the thyroid of 100 mGy for a 1-year-old infant (NERHQ, 2011a). This was confirmed by further studies on reconstruction of the thyroid doses (WHO, 2012; UNSCEAR, 2013; IAEA, 2015a; Kim et al., 2020).

B.2.4. Responders

(B14) On-site emergency responders were involved in regaining control of the damaged installations. They included power plant personnel employed by TEPCO or subcontractors, as well as personnel from the self-defense force, firefighters, and police officers. Off-site responders included personnel from various response organisations and services. They were involved in providing support to evacuees, medical care, monitoring, and sampling.

(B15) The severe radiological conditions associated with the accident led the authorities and the operator to adopt exceptional arrangements to ensure the protection of responders on-site and within the 30-km area. On 14 March 2011, the regulatory radiological criterion for their protection was temporarily increased from 100 mSv to 250 mSv. Six responders received doses in excess of this level (highest dose 678 mSv), mainly due to a lack of availability of adequate protective measures and lack of training. The average external exposure of approximately 4000 responders received in March 2011 was approximately 14 mSv (ICAFN, 2011; TEPCO, 2012). For 12 of the most exposed workers, the absorbed dose to the thyroid was in the range of 2–12 Gy (UNSCEAR, 2013). The regulatory dose criterion of 250 mSv was withdrawn gradually from November 2011 to 2012.

B.2.5. Protective actions for the early phase

(B16) As part of preparedness planning for a nuclear accident, decisions about protective actions were based on levels of exposure for the public estimated from a simulation model (ERSS/SPEEDI) (NAIIC, 2012). After the Japanese Government issued the declaration of a nuclear emergency on the evening of 11 March 2011, protective actions for the public were mainly implemented on the basis of actual plant conditions and environmental radiological monitoring that took place during the early phase of the accident.

B.2.5.1. Sheltering

(B17) The first sheltering order was issued on 11 March 2011 for residents within a 3–10-km radius of the plant, but this order was rapidly changed into an evacuation order on 12 March 2011. On 15 March 2011, residents living within a 20–30-km radius of the plant were ordered to shelter, as shown in Fig. B.2, because of further failures at the plant, including smoke at Unit 2, and an explosion and a fire at Unit 4.

(B18) Although sheltering is only intended for a short period of time to mainly reduce exposures from airborne radioactivity in the plume, residents, other than those who evacuated voluntarily, were asked to stay indoors continuously over a

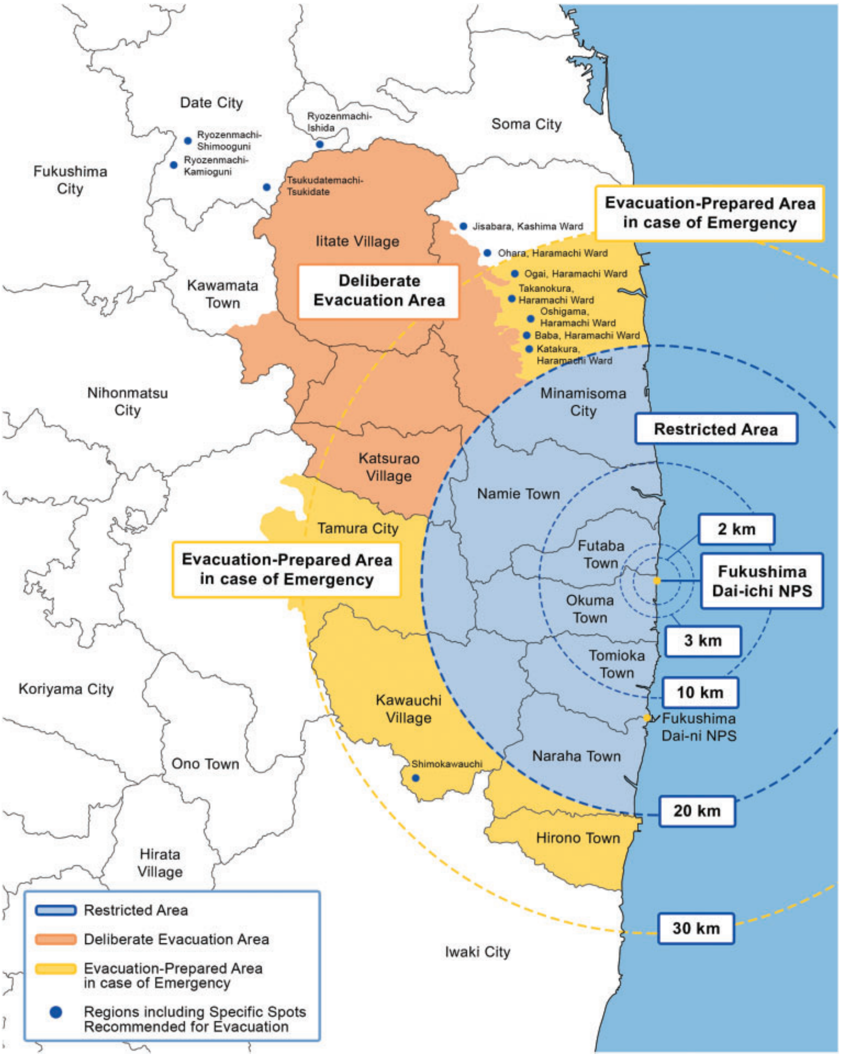


Fig. B.2. Areas and locations for which urgent protective actions were ordered in 2011 (As of 3 August, 2011). [http://www.meti.go.jp/english/earthquake/nuclear/roadmap/pdf/evacuation_map_a.pdf (As of 30 September 2020)].

10-day period. Due to difficulties associated with the provision of food and the maintenance of acceptable living conditions, the Japanese Government recommended voluntary evacuation for residents in the 20-30-km sheltering area on 25 March 2011 (NAIIC, 2012).

B.2.5.2. Evacuation

(B19) The evacuation of people from the vicinity of Fukushima Daiichi nuclear power plant began in the evening of 11 March 2011, with the evacuation area gradually extended from a 2-km radius from the plant to 3 km and then 10 km. In the evening of 12 March 2011, after the hydrogen explosion at Unit 1, the evacuation radius was extended to 20 km (approximately 78,000 residents) as shown in Fig. B.2. All these decisions were implemented based on an analysis of the situation at each unit and the overall potential risk for the entire nuclear power plant. In addition, many people evacuated voluntarily from the affected prefectures to different regions of Japan.

(B20) The evacuation process was complicated due to the damage caused by the earthquake and tsunami, and the resulting communication and transportation difficulties. A large number of residents were also forced to evacuate multiple times to different locations as the evacuation area was extended. Furthermore, when the evacuation orders were issued, many residents did not receive any accurate information about the severity of the accident and the expected period of evacuation. There were also significant difficulties encountered in evacuating patients from hospitals and elderly people from nursing facilities within the 20-km evacuation zone, which resulted in more than 60 deaths (NAIIC, 2012).

B.2.5.3. Stable iodine

(B21) Although Fukushima Prefecture started arrangements for the distribution of stable iodine tablets to the municipalities immediately after the accident, neither the Japanese Government nor the Governor of Fukushima Prefecture gave instructions to residents to take the tablets within the period of time for which they would be effective. An order for administration of stable iodine was issued for those who were being evacuated from the 20-km zone on 16 March 2011. However, Fukushima Prefecture did not follow this instruction because the Japanese Government had already confirmed that evacuation of the 20-km zone was complete. Iodine thyroid blocking was not implemented uniformly, primarily due to the lack of detailed arrangements between national and local governments (ICAFN, 2011; NAIIC, 2012). However, while Fukushima Prefecture did not give instructions to take iodine tablets, a few municipalities instructed their residents to take the tablets. A retrospective study in one of these municipalities (Miharu Town) shows that despite the very high distribution rate (94.9%), the uptake rate was only 63.5% among children because of mothers' concerns about possible side effects from taking the tablets (Nishikawa et al., 2018).

B.2.5.4. Decontamination of people

(B22) Screening surveys were implemented in the affected areas of Fukushima Prefecture to investigate body surface contamination of residents. The initial screening level used just after the accident was 13,000 counts per minute (cpm). However, the Nuclear Safety Commission recommended that this level should be increased to 100,000 cpm on 20 March 2011, based on the 1 $\mu Sv\ h^{-1}$ criterion recommended by IAEA. Most of the 200,000 people surveyed had body surface contamination below 100,000 cpm. It was reported that approximately 100 people who exceeded the screening level needed whole-body decontamination (ICAFN, 2011).

B.2.5.5. Precautionary restrictions of foodstuffs

(B23) The Japanese Government began to issue restrictions on the distribution and consumption of specific foodstuffs and drinking water when high concentrations of radionuclides were detected in samples of tap water, milk, and leafy vegetables beyond the 20-km area. For this purpose, the criteria in the regulatory guide of the Nuclear Safety Commission were adopted as provisional regulatory values by the Ministry of Health, Labour and Welfare on 21 March 2011. In April 2011, the Japanese Government developed a plan to allow food distribution to the affected population, which also provided guidelines on how to set and lift food and drinking water restrictions (NERHQ, 2011a).

B.2.5.6. Relocation and schools

(B24) On 22 April 2011, the area outside the 20-km radius where the estimated projected dose for the first year following the accident could reach 20 mSv was designated as the 'deliberate evacuation area'. The Japanese Government issued an order that relocation of people from this area should be implemented over a period of approximately 1 month. The criterion for relocation was selected by the Japanese Government with consideration of the 20–100 mSv per year band of reference levels for emergency exposure situations recommended by ICRP. Beyond the deliberate evacuation area, the areas subject to sheltering within the 20–30-km radius were designated as 'evacuation-prepared areas in case of emergency', and the existing 20-km evacuation area was established as a 'restricted area' with controlled re-entry (NERHQ, 2011a).

(B25) At the same time, after the end of the school holidays, the Japanese Government had to make decisions regarding the re-opening of schools outside the evacuation area, where high levels of radiation had been detected in school yards. On 19 April 2011, the Japanese Government decided to restrict the outdoor activities of children at schools where the dose rate in school yards could exceed 3.8 $\mu Sv\ h^{-1}$, corresponding to an estimated annual dose of 20 mSv. This criterion was selected with consideration of the 1–20 mSv per year band of reference levels recommended by ICRP for managing existing exposure situations. The public protested strongly, claiming that the criterion set to ensure the safety of children was the same as that established for the deliberate evacuation area. In May 2011, the Japanese Government issued a notification to Fukushima Prefecture to reduce the dose to school children over the period April 2011–March 2012 to 1 mSv per year, which was the long-term objective recommended in *Publication 111* (ICRP, 2009). National authorities offered financial support for decontamination of schools with dose-rate measurements greater than 1 μSv h^{-1} (ICAFN, 2011; NAIIC, 2012).

B.2.6. Protective actions for the intermediate phase

B.2.6.1. Evacuation of specific locations with high-level exposure

(B26) Monitoring results outside the restricted area and the deliberate evacuation area identified specific locations where projected exposure to residents could be higher than 20 mSv within 1 year of the accident. In June 2011, the Japanese Government began to designate these locations as 'specific spots recommended for evacuation', and several houses were identified as such by November 2011. The Japanese Government provided information to alert the affected residents on the radiation exposure levels, and supported them if they wished to evacuate (ICAFN, 2011; NERHQ, 2011b).

B.2.6.2. Lifting of evacuation for the evacuation prepared areas in case of emergency

(B27) In August 2011, the Japanese Government prepared a review of evacuation areas from the perspective of the safety of the damaged reactors at the nuclear power plant, the decrease in air radiation dose rate, and the restoration of public services and infrastructures. Based on monitoring activities carried out in the affected areas and the various actions implemented by the municipalities, the Japanese Government concluded that all the conditions for termination of the evacuation prepared areas in case of emergency had been met. After consultations were held between the Japanese Government and the municipalities, a directive was issued that the evacuation orders for these areas should be lifted on 30 September 2011 (ICAFN, 2011).

B.2.6.3. Evacuation of pets and livestock

(B28) Many pets and livestock were abandoned when people were evacuated. The short-term temporary access that was allowed in the restricted area from May 2011 provided an opportunity to evacuate the pets remaining in the area. This evacuation of pets continued over a long period with the support of various organisations (MOE, 2012). Most of the cattle from the affected areas were also evacuated, except for those in the restricted area where the livestock were abandoned following a decision by the Japanese Government in May 2011 (MAFF, 2011). These animals were culled with the permission of their owners.

(B29) In 2013, the Ministry of the Environment developed the Guideline for Rescue of Pets in the Event of a Disaster. This guidance helps local governments to make arrangements and to establish rules, guided by the principle that pets should be evacuated with their owners in the event of any catastrophe, including a nuclear accident.

B.2.6.4. Waste management

(B30) Following the accident, contaminated waste arising off-site was classified either as debris from the earthquake and tsunami, or by-products from the implementation of protective actions, including remediation activities. Prior to the accident, there was no law to regulate the disposal of disaster waste contaminated with radioactive material in public areas. Therefore, the Japanese Government established ad-hoc criteria for treatment and disposal of such waste in consultation with other relevant organisations.

(B31) The Act on Special Measures Concerning the Handling of Environmental Pollution by Radioactive Materials was issued in August 2011 and took full effect from January 2012 (MOE, 2011). The Act became the main legal instrument to deal with all remediation activities in affected areas, and associated radioactive waste. It outlined the management of contaminated areas, and assigned responsibilities to national and local governments, the operator, and the public. The Act also formalised the decontamination measures and the designation, treatment, storage, and disposal of soil and waste contaminated by radioactive material.

B.2.6.5. Decontamination programme

(B32) As decontamination was an urgent issue, the Japanese Government established a basic policy for decontamination work in August 2011, with specific targets and working principles in implementing decontamination. The Japanese Government wanted to carry out a rapid decontamination programme to progressively reduce the areas with additional radiation dose (due to the accident) higher than 20 mSv per year. In areas with an estimated additional annual radiation dose less than 20 mSv, the Japanese Government aimed to work with municipalities and local residents to implement decontamination work, so that the additional radiation dose would be reduced to 1 mSv per year or below as a long-term objective (NERHQ, 2011b).

(B33) Taking into account physical decay of radioactive material and weathering effects, the target for implementing decontamination in affected areas was a reduction in the additional annual radiation dose by approximately 50% for the general public, and by approximately 60% for children within the next 2 years. The long-term target was set to reduce the additional annual dose to 1 mSv per year or below in accordance with the recommendations of ICRP for the protection of people living in long-term contaminated areas after a nuclear accident (ICRP, 2009). To guide the decontamination works, the Japanese Government adopted the dose-rate criterion of $0.23\,\mu Sv\,h^{-1}$, including natural background (NERHQ, 2011b; IAEA, 2015b).

B.2.7. The ICRP Dialogue Initiative in Fukushima

(B34) Towards the end of 2011, the situation of those affected, particularly those evacuees who could not return home, remained precarious, despite the protective actions implemented by the national and local authorities. Persistent concerns about exposure to radiation, combined with the difficulties of daily life, had greatly degraded the well-being of individuals and the quality of life of affected communities. In this context, ICRP took the initiative in November 2011 to initiate a dialogue between representatives of national authorities and authorities of Fukushima Prefecture, local professionals, affected communities, the media, and representatives from Belarus and Norway with direct experience in dealing with the long-term

Fig. B.3. The second Fukushima Dialogue meeting in February 2012 in Date City.

consequences of the Chernobyl accident (See Fig. B.3). The objective was to facilitate discussions between stakeholders and to share the experience of communities affected by the Chernobyl accident, particularly those in Belarus, with the Japanese people. In so doing, it was hoped to find ways to respond to the challenges posed by long-term rehabilitation of living conditions in the areas affected by the Fukushima nuclear accident. For ICRP, it was also an opportunity to learn directly from the Japanese people so that improvements in future ICRP recommendations could be made.

(B35) By the end of 2019, more than 20 dialogue meetings had been held in various locations in Fukushima Prefecture with the support of local stakeholders. These meetings tackled difficult issues, particularly the treatment of contaminated foodstuffs, the education of children, the question of whether to stay in or return to the affected areas, the role of measurements, etc. They also addressed the challenges of rehabilitating living conditions in many municipalities. Tangible results have been obtained, such as bringing teachers together to examine teaching methods and tools on radiological issues. Even the purchasing and marketing policies of a large national food retailer have changed (Kotoba, 2015; ICRP, 2016; Lochard et al., 2020).

(B36) Many smaller-scale meetings were organised in the Fukushima region as a result of the dialogue meetings. In addition, exchange visits were organised among the affected people from Japan, Belarus, and Norway, enabling them to share their first-hand experiences and to take stock of the long-term challenges of rehabilitating living conditions in affected territories. Finally, the Fukushima Dialogue has promoted co-expertise processes in several communities, which has encouraged the development of a practical radiological protection culture and the implementation of self-help protective actions by many local residents (see Section 3.5).

B.3. Long-term phase

(B37) The long-term phase on-site can be considered as starting on 16 December 2011 when the Japanese Government announced ‘the re-establishment of control and the attainment of cold shutdown status regained in Units 1 to 3’, meaning that the radiation source was considered to be sufficiently secured. However, this was not confirmed in a legal document.

(B38) On 26 December 2011, the Japanese Government initiated a process to review the areas off-site where protective actions were being implemented. This resulted in the rearrangement of the restricted areas and areas to which evacuation orders have been issued, starting in April 2012. This can be considered as the beginning of the long-term phase off-site (ICAFN, 2012).

B.3.1. Responders

(B39) Following the basic policy and guidelines on decontamination work adopted in August 2011, the Japanese Government issued a notification to ensure the radiological protection of responders involved in decontamination activities. Every employer was responsible for ensuring the protection of each responder engaged in decontamination work. Essentially, the requirements for occupational exposure in normal operation were applied for all responders engaged in decontamination work, restoration, and waste management. Self-employed responders, residents, and volunteers who performed decontamination work in their local area were asked to follow the relevant sections of the guidelines for responders engaged in decontamination work by the national authority.

B.3.2. The lifting of evacuation orders

(B40) A set of conditions for the lifting of evacuation orders was prepared by the Japanese Government in consultation with the local authorities. This enabled a review of the status of areas where evacuation orders had been issued.

(B41) The conditions for lifting an evacuation order were as follows: (i) confirmation that the annual cumulative dose would be less than 20 mSv; (ii) confirmation that sufficient progress had been made in the restoration of essential infrastructures and social services, especially for children; and (iii) confirmation that extensive consultation had been held between local government and residents (NERHQ, 2011d).

(B42) On the basis of these conditions, three new areas were determined:

- Area 1, areas where evacuation orders were ready to be lifted (i.e. areas where the estimated annual cumulative dose was less than 20 mSv);
- Area 2, areas in which residents were not permitted to live (i.e areas where the estimated annual cumulative dose was more than 20 mSv); and
- Area 3, areas where it was anticipated that it would be difficult for residents to return for a long time (i.e. areas where the estimated annual cumulative dose was more than 50 mSv or the estimated annual cumulative dose was expected to be more than 20 mSv over the following 5 years).

(B43) Consultations and adjustments were made within Fukushima Prefecture and relevant municipalities. Initially, three municipalities decided to make changes in arrangements for their areas in April 2012. As shown in Fig. B.4, proposals for areas where evacuation orders had been issued were prepared in all 11 affected municipalities by August 2013. The first lifting of an evacuation order took place in Area 1 in April 2014. The lifting of evacuation orders was completed in both Area 1 and Area 2 by April 2017. For Area 3, restoration of essential infrastructure and decontamination activities started in 2018 for some designated reconstruction and rehabilitation base areas in six municipalities.

(B44) The percentage of people who returned home was less than 30% and very variable across municipalities, ranging from less than 10% to approximately 80% at the beginning of 2020 (Fukushima Prefecture, 2020). These values were dependent, in part, upon the timing for lifting the evacuation order. For the three areas,

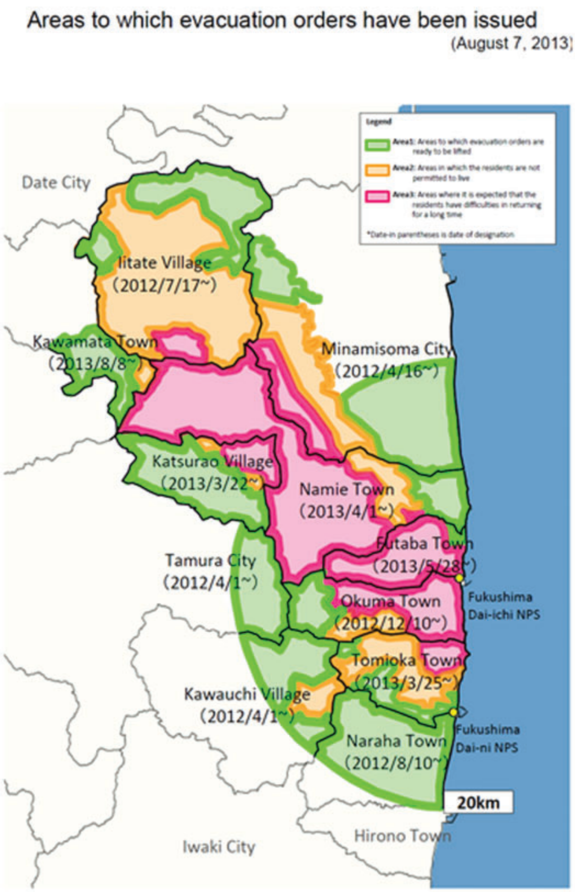


Fig. B.4. Completion of arrangements for areas where evacuation orders had been issued (as of 7 August 2013). [https://www.meti.go.jp/english/earthquake/nuclear/roadmap/pdf/20130807_01.pdf (As of 30 September 2020)]

the Japanese Government set a long-term goal of less than 1 mSv per year for the additional dose received by individuals when they return home to live in those areas (NRA, 2013). Exposures in municipalities where evacuation orders had been lifted were estimated to be in the range of 1 mSv per year for external exposure by the end of 2019 using individual radiation dosimeter monitoring (Nomura et al., 2020).

B.3.3. Foodstuff management

(B45) In April 2012, the responsible authority established new radiological criteria for radioactive caesium in food, based on an annual exposure of 1 mSv per year

(ICAFN, 2012; MHLW, 2012), thereby replacing the provisional regulatory values set in March 2011.

(B46) For better controlling internal exposure, the responsible authority established an extensive food monitoring programme to reject products exceeding the new radiological criteria. Based on information provided by the Ministry of Health, Labour and Welfare, the fraction of food from Fukushima exceeding the criteria was less than 1% in August 2014 (Merz et al., 2015). For example, the level of radioactive caesium was measured in all rice bags from Fukushima Prefecture, and fewer than 100 bags out of approximately 10 million bags were found to exceed the criterion of $100\,\mathrm{Bq\,kg^{-1}}$ (Nihei et al., 2015).

B.3.4. Decontamination and waste management

(B47) Based on the Act on Special Measures Concerning the Handling of Environment Pollution by Radioactive Materials, decontamination activities were implemented extensively in affected areas from 2012 to reduce chronic exposure from external irradiation, which was the predominant exposure pathway of people in affected areas. Pilot decontamination projects were initially conducted to provide experience, tools, and guidelines for planning and implementing efficient, safe, and cost-effective decontamination programmes.

(B48) Decontamination activities generated a large amount of contaminated soil and waste, and the Japanese Government decided to place this waste at temporary storage sites in municipalities before transferring it to an interim storage facility close to the Fukushima Daiichi nuclear power plant. The final disposal site or sites have yet to be determined. However, in case of difficulties in obtaining agreements for the selection of temporary storage sites, some of the contaminated waste has been stored temporarily in flexible container bags near the places where decontamination has been carried out. In 2016, the national authorities developed a Volume Reduction and Recycling Utilisation Technology Development Strategy to promote recycling of the soil after volume reduction as much as possible, which will reduce the volume of soil for final disposal (MOE, 2018).

B.3.5. The co-expertise process and self-help protective actions

(B49) In addition to the protective actions implemented by the authorities, co-expertise processes were adopted in several communities which favoured the development of self-help protective actions. Inspired by the ICRP Dialogue or developed independently, these co-expertise processes were initiated by different stakeholders depending on the local situation: mayors, residents, health professionals, academics, etc. (ICRP, 2016). Some of these processes carried out by local people helped by voluntary experts have remained informal, and others have given rise to formal co-operation between local authorities and expert organisations or universities (Ando, 2016; Naito et al., 2017; Takamura et al., 2018; Yasutaka et al., 2020).

(B50) Experience of these co-expertise processes has demonstrated the key role of regular dialogue between experts and affected people. Carried out in groups or in face-to-face meetings, these dialogues enabled the affected people to express their concerns about radiation-induced health risks, the future of their jobs, the impact of the accident on the family structure and cohesion, access to the forest, decontamination activities and management of the associated waste, etc. For the experts, the dialogues were an opportunity to reflect on the problems faced by the affected communities whilst enabling them to share their knowledge and experience (See Fig. B.5) (Miyazaki, 2017). These dialogues, based on listening and empathy, gradually fostered the return of confidence in experts and the authorities (Ethos in Fukushima, 2019).

(B51) The co-expertise processes supported the direct involvement of the affected people in the characterisation of their radiological situation in order to understand where, when, and how they were exposed. The provision of adequate and easy-to-use devices for measuring ambient dose rates, external exposure, and foodstuff contamination during the years following the accident greatly facilitated this involvement (Naito et al., 2015; Brown et al., 2016). Progress was also made for easier access to internal exposure monitoring. The sharing of individual exposure measurements and their interpretation with the support of experts allowed the gradual development of a practical radiological protection culture among stakeholders embarked in the co-expertise processes (Tsubokura et al., 2020).

(B52) The development of this practical radiological protection culture not only led many affected people to implement self-help protective actions for themselves and their loved ones, but also favoured the implementation of various collective

Fig. B.5. Dialogue between experts and villagers.

protective actions with the support of experts from the local community. These diverse actions could range from radiological monitoring of temporary storage of decontamination waste to the collection of mushrooms to determine their radiological quality (Orita et al., 2017; Lochard et al., 2020).

(B53) The co-expertise processes implemented in the affected areas of Fukushima have also stimulated the development of local projects to contribute to the recovery of the communities involved. Initiated by individual entrepreneurs or by local authorities, these projects have benefited from the scientific support of radiological protection experts or academics, and also from the financial support of the national authorities. Despite several positive outcomes, however, the dissemination of the co-expertise process in affected areas of Fukushima remains limited.

B.3.6. Health surveillance of the general population

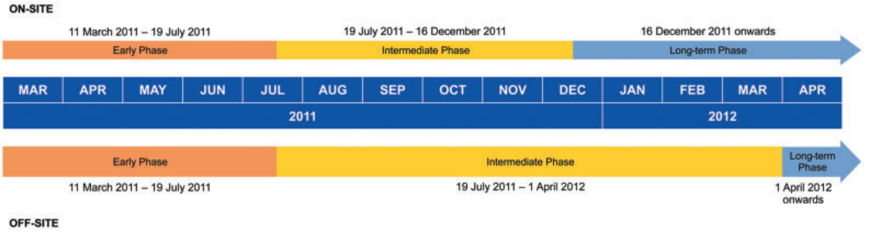
(B54) As part of the Fukushima Health Management Survey, four thyroid ultrasound examination campaigns were implemented. By June 2019, more than 220 cases of thyroid cancer had been identified in a population of approximately 300,000 individuals (FMU, 2019). This high frequency of childhood cases of thyroid cancer is clearly higher than would have been expected from a thyroid cancer registry. This observation is likely due to the systematic ultrasound screening, and needs further investigation (Ohtsuru et al., 2019). Moreover, the screening of children raised several ethical issues (Midorikawa and Ohtsuru, 2020).

(B55) The comprehensive health check-ups for residents from both inside and outside the evacuation areas, including conventional health examinations and cancer screening, revealed an increase of risk factors for circulatory diseases (FMU, 2019).

(B56) The mental health and lifestyle survey revealed that despite a reduction in the number of people suspected of having affective or anxiety disorders, such as depression, since the accident, the percentage of people who require support is still higher than that in the general population of Japan.

(B57) A specific survey to address the anxiety of pregnant women and mothers of young children was carried out and gave similar results. The survey showed a similar incidence of premature babies, low birth weight, and congenital anomalies as reported for the general population of Japan (FMU, 2019).

B.4. Timeline of the phases of the Fukushima accident



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GLOSSARY

Co-expertise

A process of co-operation between experts and local stakeholders to exploit local knowledge and scientific expertise for the purpose of understanding the radiological circumstances, and developing actions by themselves or by others to improve living conditions.

Contamination

The presence of unwanted levels of radioactive material on or in structures, areas, objects, biota, or people.

Decontamination

The complete or partial removal of contamination by a deliberate physical, chemical, or biological process.

Emergency exposure situation

An exposure situation resulting from a loss of control of a source, or from intentional misuse of a source, which requires urgent and timely actions in order to avoid or mitigate exposure.

Existing exposure situation

Existing exposure situations are exposure situations resulting from sources that already exist when a decision to control the resulting exposure is taken. These include natural sources (cosmic radiation, radon, and other naturally occurring radioactive materials) and man-made sources (long-term exposure from past practices, accidents, or radiological events). Characterisation of exposures is a prerequisite to their control.

Exposure pathway

A route by which radiation or radionuclides can reach human and non-human biota, and cause exposure.

Graded approach

The scheme recommended for implementing the system of protection in a way that is proportionate to the magnitude and likelihood of the risk, and the complexity of the exposure situation and the prevailing circumstances.

Health surveillance

The continuous, systematic collection, analysis, and interpretation of health-related data needed for the early detection of ill-health effects, and for the management and treatment of affected individuals.

Occupational exposure

Radiation exposure incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management.

Planned exposure situation

An exposure situation resulting from the deliberate introduction and operation of radiation sources, used for their radioactive properties. For this type of situation, the use of the source is understood and, as such, the exposures can be anticipated and controlled from the beginning.

Practical radiological protection culture

The knowledge and skills enabling citizens to make well-informed choices and behave wisely in situations involving potential or actual exposures to ionising radiation.

Principle of justification

Decisions that alter (i.e. introduce, reduce, or remove) the radiation exposure situation should, overall, do more good than harm. This means that by introducing a new radiation source, or by reducing existing or emergency exposures, one should achieve sufficient individual or societal benefit to offset any harm, including radiation detriment to humans and the environment.

Principle of optimisation

The likelihood of incurring exposures and the magnitude of individual doses should be kept as low as reasonably achievable, taking into account societal, economic, and environmental factors. In order to avoid inequities in the dose distribution, there must be consideration of the number of people exposed and restrictions on individual doses.

Projected dose

Dose expected to be received by individuals in the absence of protective actions.

Protective action

Action taken in emergency or existing exposure situations to reduce or prevent exposure. The action can be taken at the source, at points in the exposure pathway, or occasionally by modifying the location, habits, or working conditions of the exposed individuals.

Protection strategy

The set of combined protective actions that are implemented, for a given exposure situation and prevailing circumstance, to keep or reduce exposure to as low as reasonably achievable.

Radiation detriment

The overall harm to health incurred by an exposed group and the descendants of that group as a result of a particular exposure to radiation.

Radiological criteria

Quantitative values for practical implementation of the radiological protection system. Expressed in terms of dose or derived quantities. This generic term is used in a variety of settings and is equally applicable in all exposure situations.

Recovery

The process of remediating and rehabilitating to reflect, to the extent possible, suitable circumstances, such as those prevailing before the accident.

Reference level

A dose criterion used to guide the optimisation process in existing and emergency exposure situations. Generally expressed in terms of individual annual dose (mSv $year^{-1}$), the value of a reference level should be selected considering the appropriate time frame, individual dose distribution of the affected people, and the tolerability of risk in the circumstances. An objective is to facilitate the identification of people for whom protective efforts should be given priority.

Rehabilitation of living conditions

The process for ensuring sustainable and decent conditions for people living in long-term contaminated areas.

Remediation

The process to reduce the radiation exposure from contamination through actions to remove the contamination itself (decontamination) or to affect the exposure pathways.

Residual dose

The dose received or expected to be incurred by an individual from a given source. It can be estimated or measured, taking into account any protective actions that have been applied to the source, pathway, or individual. Residual dose applies in an emergency exposure situation or in an existing exposure situation.

Right to know

The right of individuals to be informed about what hazards they are exposed to and how to protect themselves.

Self-help protection

Informed actions taken by individuals to protect themselves, their family, and their community.

Stakeholder

A person, group, or organisation with an interest in or concern about an issue.

Stakeholder involvement

The participation of all relevant parties in the decision-making processes related to radiological protection. Also referred to as 'stakeholder engagement'.

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